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ELEMENTARY BIOLOGY

DESCRIPTIVE AND EXPERIMENTAL

BY

JOHN THORNTON, M.A.

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"ELEMENTARY PHYSIOGRAPHY," ETC.

HEAD MASTER OF THE CENTRAL HIGHER GRADE SCHOOL, BOLTON

WITH 192 ILLUSTRATIONS

REVISED AND ENLARGED EDITION

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PREFACE

This work on Elementary Biology has been prepared mainly for teachers who are preparing for the examinations of the Board of Education. The Board of Education has issued a syllabus under the title " Elementary Biology," which indicates that teachers seeking certificates are expected to obtain a general knowledge of the structure and physiology of higher plants and animals, and that this knowledge should be based in large part on practical acquaintance with a few leading types. I have endeavoured to meet these requirements, not only in the descriptions and expositions given, but also in the illustrations and practical directions. The descriptive text is intended to be clear and precise, but it has not been loaded with too many technical terms. Such as are used are explained as they occur. The illustrations are numerous, and intended to be a real help to the understanding of the text. Several of them have been specially drawn for the work, while others have been obtained by permission from the source acknowledged. I wish, however, especially to thank Professor Jayne, of the Wistar Institute, Philadelphia, as he was kind enough to supply me with the electro from which Fig. 148 is produced.

The practical directions for observation and experiment will be found partly in the course of the text and partly under the distinct head, "Experiments." Many of them are of such a nature that the student should have no difficulty in carrying them out at his own home.

It will be found that the requirements of the syllabus, "Structure in relation to movement, as represented by some simple quadruped," is met by selecting the cat as the type of animal, but I have considered it best to found this knowledge on an account of the general build of the human body, as I am convinced that this will be the most interesting and successful way.

Besides being serviceable to students preparing for the examinations mentioned, it is hoped that the book will prove useful to all teachers engaged in promoting Nature Study.

A set of carefully prepared Questions and Exercises, with occasional hints and explanations, will be found at the end of the book.

J. THORNTON.

September 10, 1902.

PREFACE TO REVISED EDITION

In order to make the book more complete for the full Certificate Examination in Elementary Science, Part II., I have added a rather long Chapter on the Structure and Habits of Frogs and Birds. It is believed that the book now contains more than enough to enable the candidate to do well in this part of the examination.

J. T.

January, 1907.

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ELEMENTARY BIOLOGY

CHAPTER I.

THE LIVING WORLD.

1. The Three Kingdoms of Nature.—As the result of simple observation, the natural objects found on the earth are often divided into three great classes or kingdoms, termed the Animal Kingdom, the Vegetable Kingdom, and the Mineral Kingdom. The three members of these classes are then described somewhat as follows:—

(*a*) Animals are bodies which live, grow, move, and possess a certain sensibility.

A worm, a butterfly, a dog, and a man, for example, belong to the animal kingdom.

(*b*) Vegetables, or plants, are bodies which live and grow, but do not move from place to place, and have no sensibility.

Grass, a rose, and an oak, for example, belong to the vegetable kingdom.

(*c*) Minerals are bodies which have not only no power of spontaneous movement and no sensibility, but no life.

A pebble, a quartz crystal, and a piece of clay, for example, form part of the mineral kingdom. Water and air also belong to the mineral kingdom, being neither animals nor vegetables. So also do all the various metallic compounds found in the earth's crust.

The above division of natural objects is often convenient to refer to, but the definition and description of each kingdom can hardly be considered complete or scientifically accurate. Some animals, for example, are fixed to one spot, and show no more movement than is seen in the rising and falling of leaves and the opening and closing of flowers, while the leaves of the sensitive plant move and respond to a gentle touch. Again, while there is no difficulty in knowing that a cat is an animal and a hawthorn bush a vegetable, yet it is very difficult to say whether some of the simplest and smallest living objects are animals or plants. There are, however, besides the properties common to all matter, certain qualities or characters that belong to all living things, whether plants or animals, and that sharply and clearly divide them from non-living bodies. Our first clear classification, therefore, of natural bodies may be thus represented :

1. Living bodies . . .	Animals. Plants.
2. Non-living bodies . .	Minerals.

We will now state the characters common to all living things, and which distinguish them from mineral bodies. Some of these distinctive properties will be better understood after the reader has been once through the book.

2. Characters of Living Bodies.—Besides the general properties belonging to all matter, living things have certain additional and distinctive qualities or characters. These special marks are—

I. Power of Growth.—All living beings **grow**—that is, increase in size by taking within themselves matter different from themselves, called food, and by transforming this matter into their own substance. A plant, for example, absorbs from the soil by its roots water and certain mineral salts that are in solution, and this absorbed nutriment spreads through all parts, and is to some extent changed and then *assimilated*—that is, made to enter into the substance of the plant itself. In animals, growth by nutrition is still more evident, so that the body of an animal, as well as that of a plant, consists of substances that are constantly being renewed from without.

Nothing resembling this growth by nutrition in living bodies takes place among minerals. It is true that a crystal of salt suspended in a saturated solution of salt exposed to the air will become larger, but this increase in the size of the crystal only takes place by the addition of similar matter to the external surface. This "growth" of a crystal by matter similar to itself added to the outside is essentially different from growth in a living being, which manufactures material like itself from materials quite different, and deposits this material in its own living substance in every part of its interior, making it, in fact, a part of itself.

II. Living Things respire.—All living matter is continually absorbing oxygen from the air, and this oxygen combines with some of the carbon in the living being, and is then given off as colourless carbon dioxide, CO_2. The absorption of oxygen in connection with the elimination or setting free of carbon dioxide is termed **respiration**, so that we may say that living things are **respiratory.**

As will be shown later, every plant, while alive, is taking in oxygen and giving out carbon dioxide (par. 57), though the process is not so active as in animals, and is hidden, to a large extent, by an opposite process carried on by the green parts of plants when in the light (par. 52).

Oxygen, indeed, may be regarded as a kind of food indispensable to the living matter of both plants and animals, while the carbon dioxide given off is a waste product. Deprived of oxygen, either alone or as it exists in the air mixed with other gases, living matter dies.

Mineral bodies show no continuous absorption of oxygen and disengagement of carbon dioxide. They may exist apart from any supply of oxygen.

III. Living Beings consist essentially of Protoplasm containing Proteids.—The matter forming a living being contains, besides other substances, certain complex compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur called **proteids**, and proteid substances are only found in nature in animals and plants. In other words, although the same chemical elements enter into the composition of mineral matter and living matter, yet these elements are united in living bodies to form compounds that do not exist in the mineral world.

Among the proteids found in living bodies are such substances as albumen, gluten, fibrin, and casein (see pars. 6 and 113). These proteid substances exist in living matter associated with water, fats, starchy and mineral matter, to form a highly complex, viscous, and granular substance termed **protoplasm** (Gk. *protos*, "first;" *plasma*, "mould or form"). Protoplasm, therefore, may be called the substance that forms the essential constituent of living matter, while proteids are compounds forming the essential basis of protoplasm. "It has been found that so long as any sign of life is visible, this protoplasm is in a continual state of slow combustion, absorbing oxygen from outside and decomposing with the liberation of energy; and whilst some of the products of decomposition are cast off, others apparently reconstitute the original substance by combining with some of the materials of the food. The energy liberated is the cause of the movements which constitute the visible manifestation of life."[1]

While, therefore, mineral bodies consist of comparatively simple chemical compounds that often undergo no structural change for long periods, living bodies consist of highly complex protoplasm that is constantly taking in new material as it lives and grows, and as constantly giving off waste products and expending energy. Waste and repair go on continuously in every living organism. But sooner or later the process of restoration ceases, and the organism ceases to live. When life ceases, the body becomes subject to external agencies alone, both physical and chemical, and these at last reduce it to simple compounds that pass into the air and soil.

IV. Living Beings move spontaneously and react to Excitation (Stimulation).—In living bodies of all kinds, motion of a part or whole often occurs from some internal impulse or condition without any traceable outside influence, but no such spontaneous motion occurs in stones or other mineral bodies.

---

[1] "Zoology," by Shipley and Macbride.

Living organisms are also **irritable**—that is, possess a power of responding to mechanical, thermal, or other stimulation by action of some kind.

It is true that movement of one sort or other is more marked in animals than plants, but in every plant there is constant movement of matter in its interior. There is also the movement of young shoots, of twining stems and tendrils, as well as the rising and falling of leaves, and the opening and closing of flowers.

V. Living Bodies have a Power of Development and Reproduction.—If we take a pea or bean from a last year's plant and sow the seed in ground where there is warmth and moisture, the grain will germinate and produce a plant which will bear flowers and seeds. At the end of the season the plant dies, having passed through a series of changes forming its life-history, but each detached part called a seed is able to germinate in its turn and produce a plant like its parent. A similar life-history, often of long duration, is found in other plants, and all are able to reproduce their kind.

It is the same among the living beings known as animals. A bird produces an egg which contains the rudiment or embryo of a similar bird ; for, when the egg is kept at a suitable temperature for a certain time, the embryo grows and develops by making use of the food material in the white and yolk, and in due time a young bird breaks its way through the shell and grows up. When grown up, a male and female bird give rise to fertile eggs from which other birds arise, the parents at last growing feeble and dying.

As the student progresses in his studies, he will find that all other animals are produced and give origin to others in a similar or analogous way. We therefore see that living beings take their origin in a germ (a spore, a seed, or an egg) that was developed in a parent, and the matured offspring is like the parent. The non-living or mineral world has no such origin as living matter, nor any such power of reproduction.

We see from the above-numbered statements that there are at least five distinctive co-existing marks that distinguish the objects of the living world from the objects of the non-living or mineral world; that living, in fact, consists of performing the processes called feeding, breathing, feeling, and multiplying; and that living matter is a highly complex, assimilating, respiring, moving, sensitive, and reproducing substance.

A body showing the phenomena of life and attended by structural changes as a result of its living processes is often spoken of as an **organism** and as consisting of **organized** matter. Organism as thus used is equal to living being.

The science that treats of organized or living things is called **Biology** (Gk. *bios*, "life," and *logos*, a "discourse"). The branch of Biology that treats of plants is called **Botany** (Gk. *botane*, "a plant"), and the branch that treats of animals **Zoology** (Gk. *zoon*, "an animal").

3. A Simple Living Creature.—If we examine under the microscope a drop of water taken from the surface of the mud at the bottom of a stagnant pool, we may often notice one or more specks of a jelly-like substance. These specks are slowly but frequently changing their shape. Each speck, in fact, is of irregular shape, and moves with a kind of flowing motion; the locomotion being caused by the streaming forward of the substance into projections or processes at some points, and the withdrawal of processes at other points. The tiny object we see is a living creature called an **amœba**. Careful scrutiny under a high power of the microscope will show that the jelly-like mass forming the amœba shows a clear outside and a rather granular interior. There is also seen with a high power a denser central body called the **nucleus**, and usually a clear space called from its action the pulsatory **vacuole**.

The jelly-like mass of which the amœba consists is present in all living matter, and is called **protoplasm**. Such a minute mass of nucleated protoplasm is the unit mass of living matter, and is known as a **cell**. An amœba is therefore a living creature consisting of a single cell. Chemically considered, protoplasm is a mixture of water and various solids, the chief of which are chemical compounds called proteids and carbohydrates. The amœba manifests life not only by its motion, but in several other ways. It undergoes waste, giving off carbon dioxide and other waste products, and to repair this waste it takes in food. It feeds by putting forth a process round a particle of food and gradually engulfing it, the food-particle undergoing digestion in the interior, and being changed into the ingredients of protoplasm by assimilation. Any particle that is indigestible is excreted. The taking in and digestion of food not only repair waste, but lead to an increase of the quantity of protoplasm, so that an amœba **grows.** An amœba responds to certain excitations or *stimuli*, such as warmth and shock. Gentle warmth increases its movement, a sharp shock checks its movement. An amœba is, therefore, said to be **irritable.** It can be shown that an amœba breathes by taking in at every part of its surface oxygen dissolved in the water, and giving out carbon dioxide at any part. In pure distilled water that contains no dissolved oxygen the amœba cannot live. It also possesses the power of reproducing itself, for on careful watching an amœba for some time we may often notice that the creature becomes constricted and divides into two, the detached portion performing all the actions just described (Fig. 1). The amœba, therefore, although possessing no separate parts or organs, such as mouth, stomach, heart, and lungs, to perform its separate vital functions, is yet a distinct living creature as much as a bean or a man, and is quite different from a particle of clay or a grain of sand. The amœba is, in fact, one of the simplest of living creatures.

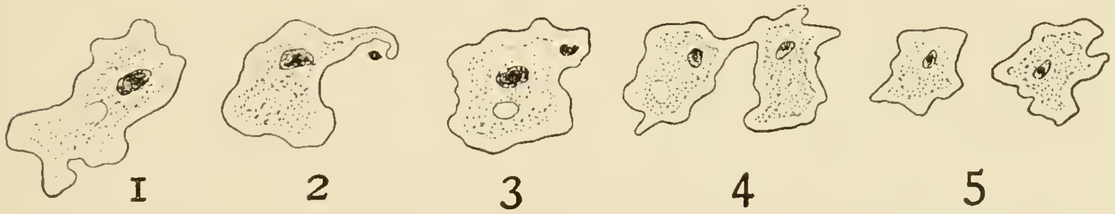

Fig. 1.—An amœba, showing granular protoplasm, nucleus, and small vacuole. At 2 it is throwing out a process to take in a particle of food; at 4 it is in process of dividing into two, the nucleus having undergone division; at 5 the division into two is complete, each part containing its own nucleus.

4. Organs and Tissues.—The simplest plants and animals are those whose bodies are simplest in structure and which perform the living processes, such as feeding, breathing, moving, and reproducing in the most simple way. As we have just seen, an amœba consists of a single mass of nucleated protoplasm called a *cell*, and this organism performs all the various life-processes without having any portions set apart for these processes. Any part seems capable of taking in food, responding to a stimulus, or putting out a process. For reasons which will shortly be understood, the amœba is regarded as an animal. There are, also, plants that have the same simple structure and that consist of a single cell.

In the higher plants and animals, however, the bodies are composed of separate distinct parts doing different functions or kinds of work. Such a distinct part is called an "**organ.**" An **organ**, then, is "a part of the body of a living being definitely fitted to perform some special function for the general benefit of the whole." Thus in an ordinary flowering plant, like the wallflower, we find such special parts or organs as the **root,** the **stem**, the **leaves**, and the **flowers.** The root serves to fix the plant to the soil and to absorb the liquid nutriment from the soil, while each of the other organs, as we shall see later, is adapted for certain special functions. In the higher animals, the separation of the body into organs is still more marked. As examples of such organs, we need only name the heart as the organ for the propulsion of blood, the eye as the organ of sight, and the muscles as the organs of motion and locomotion.

An examination of the organs of any living body will soon reveal that each organ is made of different kinds of materials called textures or **tissues.** A leaf of a plant, for example, on being pulled to pieces, may be easily seen to contain a soft tissue that forms a great part of the blade, and a tough fibrous tissue forming the stalk and the leaf-veins. With the aid of a microscope the materials of the leaf may be further distinguished.

In our own bodies, or in those of any of the higher animals, we can readily distinguish different kinds of substance, *i.e.* different tissues. There is, for example, the red flesh or **muscular tissue**; the soft greyish-white matter forming the brain and nerves, which is called **nervous tissue**; the hard compact substance forming bone or **osseous tissue**, and others. The various tissues are, as it were, the different kinds of building materials that enter into the structure of a living body, and it is by a combination of tissues that an organ is formed, each organ answering to a particular part of a complex machine, but all associated and so co-ordinated as to work together for the general advantage.

We have thus separated a living body into **organs**, or parts with a special function to discharge, and we have then seen that an organ is made up of one or more **tissues**. But with the aid of the microscope the division can be carried further, for each tissue consists of a number of minute units called **cells**, or else of units formed from cells. A cell is a minute mass of protoplasm with a nucleus, and it usually possesses a wall or limiting membrane. **All plants and animals have a cellular structure**, the cells being either simple spherical or polygonal sacs, or forms derived from these. There thus arise different kinds of cells and of cell products.

The cells of each tissue are like one another and do the same kind of work, but they differ somewhat from the cells of another tissue which do another kind of work. As just stated, tissues are arranged and bound together into instruments or organs, each organ of a plant or animal usually having one of the tissues composing it as the important one in relation to its special work.

We may **classify** tissues and organs according to the most distinctive character and function in each case. We have (*a*) **supporting** tissues and organs, whose work is mainly mechanical; (*b*) **nutritive** tissues and organs, whose function is connected with the reception and use of food-materials; (*c*) **motor** tissues, connected with the movement of parts of the body and of the body as a whole; (*d*) **sensitive** or irritable tissue, whose business it is to respond to external excitations called stimuli; (*e*) **protective** tissues, that cover free surfaces; (*f*) **reproductive**

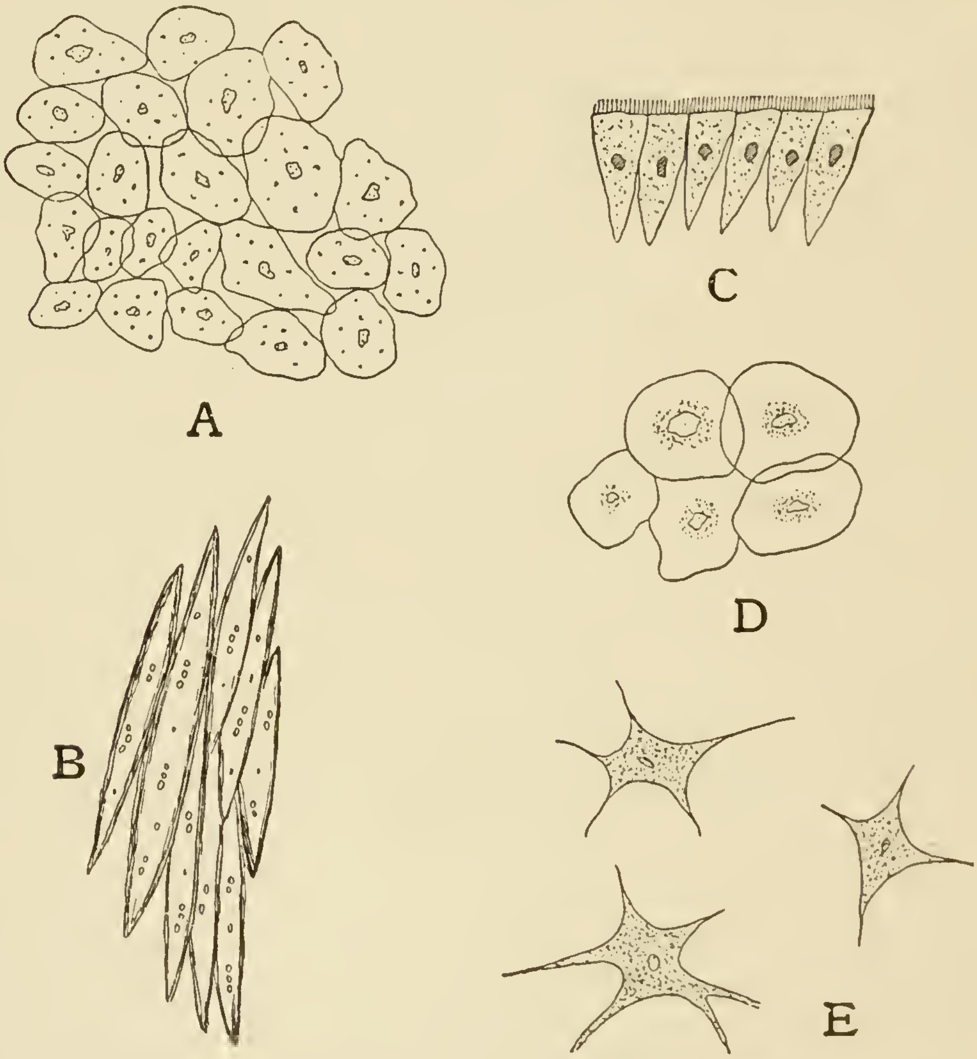

FIG. 2.—Different kinds of cells, much magnified. A, young plant cells; B, wood cells; C, ciliated animal cells; D, flattened cells; E, nerve cells.

tissues, that are concerned in the production of offspring; and in higher animals most manifestly (*g*) **co-ordinating** tissues, as observed in the action of the **nerve** tissue of the brain and its connections.

The classification of *organs* according to function can be made more easily in the case of animals than in the case of plants; for a plant organ, as a leaf, serves several purposes at the same time, more so than in the case of animals, as we shall learn later. Accordingly, we have in the higher animals not only organs connected with the great life-processes of respiration, digestion, excretion, etc., but a *system or set of organs* connected with each of these processes. The digestive organs, for example, include parts of the mouth, the stomach, the liver, the pancreas, and the intestines. In a later chapter we shall describe the organs of respiration, circulation, and digestion in some detail.

5. **Biological Division of Labour.**—In early ages, and under primitive conditions of society, every man used to make the things he required from the materials he himself obtained from nature. Every man of an uncivilized tribe was his own hunter, toolmaker, tailor, shoemaker, etc. As a consequence every process was but slow and laborious, and the result but poor. Gradually, however, men found that greater and better results could be acquired by confining the efforts of each to one kind of work, and obtaining from other special workers, by exchange, the other things that they needed. The various kinds of work belonging to daily life were thus distributed or *divided* among the workers, and there arose distinct occupations. Some became farmers and raised grain, and when they wanted protection for their feet, they gave some of their grain in return for the shoes made by those who confined their work to shoemaking. From this division of labour quicker and better results were obtained. By confining attention to one kind of work the worker becomes more expert and skilful, and does the work with the least expenditure of energy and material. The farmer, shoemaker, tailor, etc., however, only illustrate a moderate division of labour, for the principle can be extended until there is a vast number of distinct kinds of work—until one man no longer makes shoes, but only shapes toe-caps or puts on the heel. In a modern shoe factory at

least fifty different workers take part in making a single shoe. It may also be noticed that besides the increase in the efficiency of the work, owing to the increase in the division of labour, there arises in the community, and in each factory even, the need for a mechanism to distribute the various products to the parts where they are needed, and also the need of a regulative mechanism to arrange and co-ordinate the various activities for the general benefit of the whole. Modern society thus becomes, as regards its industries, a very complex structure of mutually dependent parts.

Much in the same way as different occupations arise owing to division of labour in a civilized state, so the various functions of a living being become attached to special parts of the body in all higher plants and animals. There is thus a **biological division of labour**, or a "division of physiological labour."[1] Each of the different organs has its own function, and all are so connected that they work together for the welfare of the whole body. To one organ or system of organs is assigned the work of nutrition, to another the work of respiration, to another the duty of responding to stimuli, and so on. The higher we go in the plant or animal world, the more complex does the body become in proportion to the degree in which the different functions of life are assigned to different parts, and this complexity of the body is due to a specialization or differentiation of parts for special work. We speak of a plant or animal as being high or low in organization according to the degree of **differentiation** that it exhibits—that is, according to the extent of the setting apart of special organs for special portions of its life-work.

[1] "The expression 'division of physiological labour' was invented by the great French physiologist, Henri Milne-Edwards, to express the fact that a sort of rough correspondence exists between lowly and highly organized animals and plants on the one hand, and lowly and highly organized human societies on the other" (Prof. T. J. Parker, "Elementary Biology").

The biological "division of labour" can be recognized and studied in both divisions of the living world. In the plant world the simplest plants are either single cells or collections of similar cells, each one of which is able to carry on all the various life processes—feeding, respiring, multiplying, etc. The algæ, lichens, and fungi are cellular plants without true root, stem, or leaves. In mosses we may distinguish a kind of stem and leaves, but there are no true roots, the root-like rhizoids serving only for attachment. But in the ferns these various parts are all present, as the life-work of these plants requires that special portions should be set apart for certain definite duties.

The division of labour is found not only in the external parts, but in the minute internal structure of the plants. The plants below ferns are termed **cellular plants**, as they are made up of nothing but typical cells, but in **ferns** and **flowering plants** the microscope shows besides cells what is termed "vascular tissue" (Lat. *vas*, "a vessel"), that is, a tissue which consists mainly of minute tubes that serve as conducting vessels, and hence both these great plant groups—ferns and flowering plants—are termed **vascular plants.** Flowering plants are, however, of a higher order than ferns, as the organs and tissues are more highly specialized for the work of nutrition, support, and especially for reproduction.

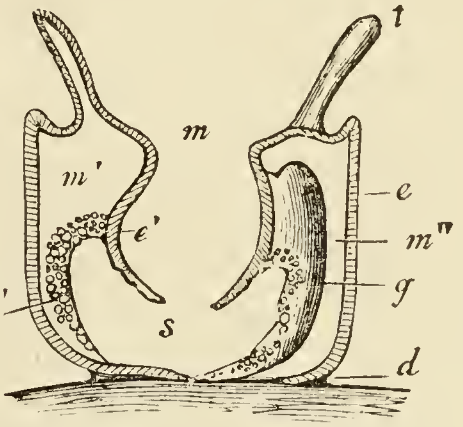

Fig. 3.—Vertical section of a sea-anemone, showing m, the mouth, leading into a stomach, which leads into the body cavity s; m' and m'', partitions in the body cavity; e, ectoderm or outer coat; e', endoderm or inner coat; t, tentacle; t', ovaries; d, disc of attachment. (From Macalister's "Morphology.")

In the case of the animal world, progress from the simple to the complex, from the lowly organized to those of the highest grade, is clearly evident. From an animal like the amœba, which eats, and breathes, and feels, and moves with any part of its body, and which has neither tissues nor organs, we find a progressive change from the general to the special. We may, for example, next pass to an animal like the *sea-anemone.* This is a brightly coloured animal found in the sea near the shore, where it may often be seen with its tentacles expanded and looking like a flower. It may also be found with its tentacles withdrawn as a mere rounded gelatinous mass clinging to a rock from which the tide has receded. Now, this animal is of a higher type than the amœba, for there is in the cells composing it some difference in function, that is, some small division of labour ; for some cells are modified so as to devote themselves to food-taking and digestion, some are specially sensitive, and some specially contractile. There is an approach to tissues and organs, but although there is a kind of mouth between the tentacles leading into a stomach, there is no heart, no blood, no special breathing organs, no eyes nor limbs. The animal usually multiplies by small eggs developed in ovaries in the body cavity and emitted at the mouth.

A higher type of animal than the sea-anemone is represented by one of the **Mollusca**, a division which includes oysters, mussels, and snails. Although it has no proper limbs, a bivalve like a mussel has a mouth leading into a true digestive canal,

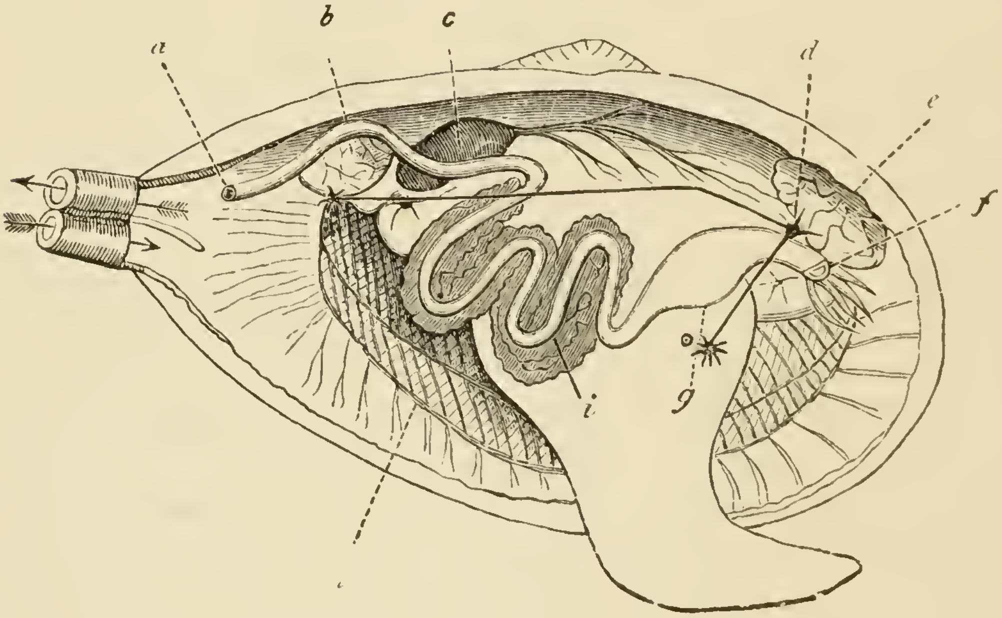

FIG. 4.—Diagram of the anatomy of a Lamellibranch, or bivalve mollusc. *g*, stomach, *i*, intestine surrounded by the liver. The two tubes on the left marked by arrows are the canals of the siphon. The current of water enters by the lower and gets out by the upper tube. *a*, the anus ; *b*, hinder abductor muscle, under which is the parieto-splanchnic nerve ganglion ; *c*, heart ; *d*, nerve ganglia ; *e*, fore abductor muscle ; *f*, mouth with labial tentacles, usually only two in number ; the dotted line from *g* passes between the pedal ganglion which lies in front of it and the ear-vesicle ; *h*, gills. The right valve of the shell has been removed, and the right side of the mantle, to show the internal structure. (From Macalister's "Zoology of the Invertebrate Animals.")

a heart which propels blood, a two-lobed mantle under the folds of which are gills or breathing-organs, masses of nerve matter (ganglia) in connection with one another and with muscular and other tissue. A tube or siphon exists at the hinder end of the body, with an upper and a lower passage. Food and water enter the lower passage and pass over the gills and before the mouth, the excreted matter and the water coming from the gills being discharged by the upper tube of the siphon. Compared with the sea-anemone, there is clearly an increased differentiation of structure accompanied by an increased division of labour (Fig. 4).

Consider now an insect[1] like the bee, the fly, the butterfly, the ant, or the beetle. Such an animal shows a still further setting apart of special portions of its body for the various processes that constitute living. Insects are the most highly organized of the invertebrates, or animals without backbone. They have jointed bodies and limbs moved by a system of muscles ; they breathe by means of tracheæ, or air-tubes, that pass from the outside and are widely distributed in their tissues ; they have a tubular heart of many chambers and a system of blood-vessels ; and they possess a digestive system consisting of mouth, gullet, stomach, and intestine. Moreover, insects have a nervous system that includes a kind of brain, a system of connected masses of nervous matter (ganglia), and certain organs of sense. The head of an insect possesses a pair of compound eyes and jointed feelers, or antennæ. The mouth is a somewhat complex structure varying in shape according to the method by which the insect feeds. The appendages include two lips, an upper and a lower one, and between the lips two pairs of jaws placed vertically. These jaws are of various forms in different insects, being in some cases adapted for biting and in other cases for sucking. In butterflies and moths, for example, the lower jaws or maxillæ are greatly elongated, each forming a half-tube, so that when put together they form a kind of trunk or proboscis by which the honey of flowers is sucked up (Figs. 5 and 94). A bee has also a kind of tubular trunk, but it is much shorter than that of a butterfly or moth, and cannot, like that of those insects, be rolled up (Fig. 93).

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[1] The true insects are invertebrate animals whose bodies are divided into a head, a thorax of three segments, each of which has a pair of legs, and an abdomen of ten segments. There are generally two pairs of wings, but there is sometimes only one pair, and sometimes none. The word "insect" is often loosely used of any small invertebrate.

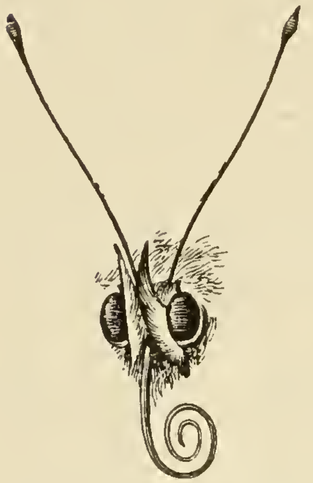

Fig. 5.—Head of moth, showing antennæ turned up and eyes with the hairy cushions termed labial palps between the eyes. The proboscis partly coiled is also shown. (From Macalister's "Zoology of Invertebrate Animals.")

The highest or primary group of animals is termed the **Vertebrata**, and includes all the animals possessing an internal skeleton with a flexible backbone, a true brain in the head, a spinal cord, and a gradually increasing and specialized nervous system.

The subdivisions of the group of Vertebrata are: (*a*) **fishes**; (*b*) **amphibians** (frogs, toads, etc.); (*c*) **reptiles** (snakes, lizards, etc.); (*d*) **birds** and (*e*) **mammals.** By comparing these subdivisions of the vertebrata we find a gradually increasing complication of structure and a corresponding specialization of work in various organs, the great life-processes not only having distinct parts of the body devoted to them, but subsidiary processes having special parts executed by distinct organs.

(As a good example of increased specialization and division of labour, compare the structure and work of the simple digestive canal of a mollusc like the oyster with that of a quadruped like the cat (see Figs. 4 and 146)).

The Mammalia or suck-giving animals form the highest group in the Animal Kingdom, since they possess the most complex organization adapted to perform the greatest number and variety of actions with the most advantage to the individual. There is in them, in other words, the greatest physiological division of labour. They breathe by lungs in which the air-tubes terminate in air-cells, they have a heart that provides for a double circulation, and the thorax and abdomen are separated by a partition or diaphragm, which is not the case in birds. The females produce their young alive and feed them for a time on a special fluid, the milk, secreted by mammary glands. The highest mammal, man, is distinguished among other things by the upright position, by the adaptation of the hand to the greatest variety of purposes, and by the most highly developed brain of all animals.

6. Organic and Inorganic Substances.—Every separate living being, whether plant or animal, however small or great, is sometimes termed an organism. We have just learnt the distinguishing properties of living beings, *i.e.* the properties that mark them off from the non-living world. The various substances that are built up or produced by organisms came to be called **organic substances**, and organic chemistry was defined as "the chemistry of the compounds produced by plants and animals." On the other hand, substances obtained from the crust of the earth, that is, from the mineral kingdom, were called **inorganic substances**. Inorganic chemistry is the chemistry of the substances that neither are nor have been part of plants or animals—the chemistry of the metals and metallic compounds of the earth's crust, including water and air.

With these ideas of the two classes of substance, it is easy to see that sugar, starch, albumen, and fat are organic substances, while common salt (sodium chloride), chalk (calcium carbonate), and quartz or silica are examples of inorganic substances.

It was at one time thought that organic substances as defined above could only be obtained from plants or animals. But many substances obtained from plants and animals, *e.g.* urea and indigo, can be produced artificially by the chemist, and many new substances of similar nature have been built up in recent years. A distinctive mark, however, of all these substances, whether derived from organisms or produced artificially, is that they contain the element **carbon** as the central or grouping element. This has led to the modern description of organic substances as **carbon compounds**, for every organic substance is a compound of carbon with one or more other elements. Carbon itself, however, in its various forms—charcoal, soot, diamond—is regarded as belonging to inorganic bodies. So also is its commonest compound—carbon dioxide, CO_2. All other compounds of carbon may be regarded as organic substances, and the number of them is very great. An account of them is given in books on organic chemistry, which is now often defined as **the chemistry of carbon compounds.**

The carbon in organic substances usually forms a compound with one or more of the following elements: hydrogen, oxygen, and nitrogen.

Among organic substances consisting of the two elements carbon and hydrogen are—*marsh gas*, *paraffin*, *vaseline*, and *turpentine.*

Among organic substances which are compounds of the three elements carbon, hydrogen, and oxygen are—*starch*, *cellulose*, *sugar*, *fat*, *alcohol*, and *acetic acid.* Those compounds of carbon, hydrogen, and oxygen in which the hydrogen and oxygen exist in the same proportion as in water are termed **carbohydrates.** Starch and sugar are carbohydrates.

An important class of organic bodies found in all plants and animals contains nitrogen in addition to carbon, hydrogen, and oxygen. These nitrogenous organic compounds are termed **proteids**, and have been already referred to (par. 2). Examples of proteids are *albumen* (found in the white of egg), *gluten* (found along with starch in flour), *fibrin* (found in blood and lean meat), and *casein* (found in cheese).

The various parts of plants and animals are formed of some mixture of organic compounds with a good deal of water and a small quantity of solid mineral matter.

When organic substances are burnt, the hydrogen takes up oxygen and forms water, which is driven off as vapour by the heat, and the carbon also seeks oxygen in order to form carbon dioxide. If the supply of oxygen is limited, part of the carbon is left as a black residue, for carbon itself is not volatile. This suggests a simple test which often enables us to decide whether a substance is organic or inorganic, for no inorganic body on being heated leaves a residue of carbon.

Experiments.—Heat a small piece of dry starch in a test-tube held over a Bunsen flame. Observe that it soon begins to char, and that droplets of water condense on the cooler parts of the tube. A black residue of carbon remains. That this black residue is carbon could be proved by heating it in a glass tube and passing a stream of air over it, when it would unite with oxygen to form carbon dioxide, as would be seen on passing the gas produced into lime-water.

On heating common salt or alum in a test-tube in the same way as the starch was done, no black residue will be obtained.

Besides starch, many other organic substances that are solids show a similar charring or carbonization on being heated in a limited supply of air or oxygen. If wood, for example, which consists mainly of an organic substance called cellulose, be heated in a plentiful supply of air, there is left only a little ash, which is

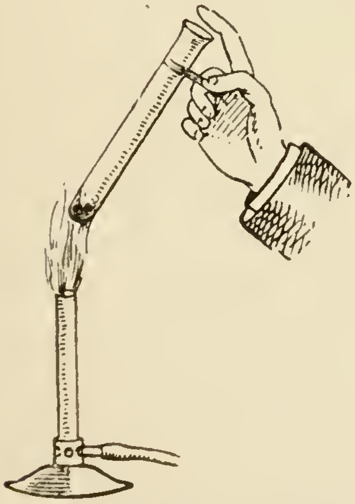

FIG. 6.—Showing that starch is an organic compound containing carbon.

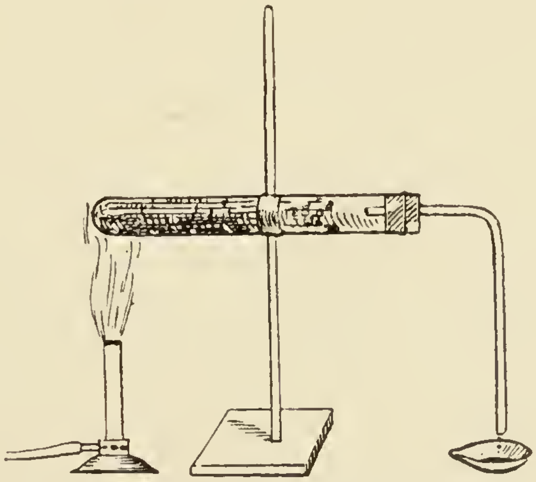

FIG. 7.—Preparing carbon from wood, and collecting the water, etc., driven out from it.

incombustible mineral matter. If, however, some chips be placed in a test-tube and heated as indicated in Fig. 7, water-vapour and certain volatile products pass off, and a mass of wood charcoal remains in the tube. The blackening of the meat when roasted before too hot a fire, shows that it contains organic substances. Of course, organic substances that are gases or liquids cannot be heated in the above way to show that they contain carbon, as they would pass off into the air. Other methods, however, can be employed.

We may now tabulate the differences that have been indicated between organic substances and inorganic substances, each distinction having some value, though the modern definition of organic chemistry is the most important one.

ORGANIC SUBSTANCES ARE—	INORGANIC SUBSTANCES ARE—
1. Substances that are or have been produced by living beings.	1. Substances that neither are not have been produced by living beings.
2. Substances belonging to the animal or vegetable world.	2. Substances belonging to the mineral world.
3. Complex compounds of which carbon is the fundamental element.	3. Metals and simple metallic compounds not directly connected with living bodies either in origin or nature.
4. Mostly compounds of carbon with hydrogen, with hydrogen and oxygen, or with hydrogen, oxygen, and nitrogen.	4. Compounds formed by the union of two or more of any of the seventy elements, except the compounds described opposite.
5. Substances which, if solid, char or leave a residue of carbon when heated in a limited supply of air.	5. Substances which, on being heated, never leave a residue of carbon.

7. Differences between Plants and Animals.—So far we have used the words **plant** and **animal** without endeavouring to draw any distinctions between these two great divisions or branches of the living world. We will now point out some of the ways in which a plant differs from an animal. The differences between the two are easy enough to see in the higher forms, and will be better understood after some knowledge of the structure and functions of one or two members of each branch has been obtained. In some of the lower forms, however, the distinction is difficult, and it is not always possible to say whether in these cases the creature is an animal or a plant.

The tree of life has been compared to the letter **V**, where the two branches are united below, but wide apart above. We know that although plants and animals have a number of points of resemblance, as stated in par. 2, yet in the higher forms there are certain differences and distinguishing marks.

One special characteristic of animals is movement, especially movement from place to place, called locomotion (Lat. *locus*, " a place "). We so naturally associate movement with living animals that if we see a fly, a bird, or a mouse at rest, we try to touch it, in order to see whether it will stir or not. Animals, on the whole, are much more active, and therefore much greater spenders of energy, than plants.

But the distinguishing mark of movement is not so evident in some of the lower animals, such as sponges and sea-anemones, which remain fixed to one spot.

In both plants and animals there is a continual waste of substance, and a continual conversion of food into protoplasm to make this waste good. The most marked distinction between plants and animals will be found in the nature of the food material that repairs this waste in each case. Plants live on simple inorganic materials derived from air and dissolved out of the soil, so that the food is liquid or gaseous in form, and they are able to convert these inorganic substances into the complex organic substances that form their tissues and their storage food-material. Animals, on the other hand, cannot convert inorganic materials into protoplasm, but must make use of the complex organic substances already worked up by plants or supplied by the tissues of other animals that have lived on plants. They take food, for the most part, in a solid form, the carbon in the starch or sugar consumed, and the nitrogen in proteids. The fact that the amœba takes in solid food is one indication of its animal nature.

Connected with the difference just noted is the contrast between the comparatively rapid conversion of the potential energy of food by animals into the kinetic energy of motion and locomotion, and the slow conversion of the kinetic energy of sunlight into the potential energy of the stored food-stuffs by plants. Waste and repair are, in fact, much more active in the higher animals than in plants.

8. Mutual Dependence of Plants and Animals.— From what we have already learnt, it is easy to see that plants and animals have certain relations to each other, and that one supports the other to a certain extent, so that there is some mutual dependence between them.

In the first place, we may note that the leaves of plants and the lungs or other breathing organs of animals perform opposite kinds of work, and have opposite effects on the air. Leaves absorb carbon dioxide and give out oxygen and the lungs absorb oxygen and give out carbon dioxide. It is true that plants also use a small quantity of oxygen, and give off some carbon dioxide, but the contrary action in plants is far the greater. It is clear, therefore, that plants and animals supply each other with a certain gas which is a necessity of life to each, and in this way are mutually dependent.[1]

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[1] It should not be supposed that this contrary effect of animals and plants on the atmosphere just balance each other. Dr. Macdougal says, "A single person throws about two pounds of carbon dioxide into the

There is another way in which the mutual dependence of plants and animals is shown. Plants obtain their nitrogen from the nitrates and ammonia compounds in the soil. Animals live on plants, either directly or by feeding on other animals that live on plants. One result of the continuous waste of animal tissue is that certain nitrogenous compounds (chiefly urea) are excreted, and thus reach the soil again, so that plants are again able to make use of them. In other words, material required by animals is supplied by plants, and the animal in its turn supplies material needed by the plant. The same matter is used over and over again in life, at one time forming a part of animal tissue, at another time part of plant tissue—an interchange or give and take going on continuously.

Plants, as we shall see later, derive their food almost entirely from the inorganic or mineral world, and as animals obtain their food materials either directly or indirectly from plants, we see that the members of the "three kingdoms of nature," referred to in par. 1, are all related to one another and inter-dependent. Without the mineral kingdom there could be no plants, and without plants no animals.

atmosphere daily, and the total product of the human race for twenty-four hours is twenty-seven or twenty-eight hundred million pounds. The breathing of the lower animals and plants and the products of fire bring the total amount of carbon dioxide produced daily by living beings directly and indirectly to about six thousand million pounds. Fifty square yards of leaf surface will take up as much carbon dioxide as may be thrown off by a single person, and furnish as much oxygen as he would need. When the immense area of the leaves of all the plants in the world is considered, it is found at the extremest low estimate that the vegetable world uses more than twice as much carbon dioxide as may be produced by living agencies, and gives off twice as much oxygen as they consume. No appreciable change has ever been found in the composition of the atmosphere with respect to these gases, however, and it must be concluded that other agencies are at work which use these gases; otherwise the air would be growing poorer in carbon dioxide and richer in oxygen." See Question 3, page 265.

CHAPTER II.

THE BIOLOGICAL IMPORTANCE OF AIR, WATER, CARBONIC ACID, STARCH, AND SUGAR.

9. Air and Living Beings.—We know that the atmosphere or air is a mixture of gases, and that free oxygen forms about one-fifth the volume of the air. Experiment and observation teach that every living creature needs a constant supply of oxygen. The protoplasm of which living matter consists is continually undergoing a more or less slow process of oxidation, so that every animal and plant, as long as it is alive, takes in from the medium in which it lives (air or water) the oxygen it needs for this process. Oxidation produces energy, and it is the energy thus produced in a living being that enables an organism to carry on many of its life-functions. The union of the oxygen with some compound of carbon in the tissues gives rise to carbon dioxide, and the process of taking in oxygen and giving out carbon dioxide is called **respiration.** The respiration of plants is treated of in Chap. IX., and the respiration of animals in Chap. XVII.

10. Carbonic Acid and Living Beings.—In an earlier course we have learnt that carbon dioxide, or carbonic acid,[1] is a gaseous compound of carbon and oxygen represented by the formula CO_2. This gas is heavier than air, does not support combustion or animal life, and when passed into lime-water turns it turbid or milky, owing to the formation of a white solid compound. The property of turning lime-water milky is, in fact, the distinguishing test for carbonic acid gas.

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[1] The name "carbonic acid" ought in strictness to be applied only to the compound formed when the gas carbon dioxide (CO_2) dissolves in and unites with water ($CO_2 + H_2O = H_2CO_3$). The term "carbonic acid" is, however, in almost general use for the gas itself in ordinary life.

Carbonic acid plays an important part in the living world. As stated in previous paragraphs, all living beings respire—that is, take in oxygen and give out carbonic acid. With regard to animals, this is the only interchange between them and the air. But the green parts of plants, when in the light, use the carbonic acid of the air as a kind of food, for they set free the oxygen of this gas and retain the carbon. The carbon is not retained as carbon, but is used along with water to build up some form of carbohydrate in the plant, as will be more fully explained later. The amount of oxygen set free and restored to the air by plants is much in excess of that used by them for respiration. The net result is that plants reduce the quantity of carbonic acid in the air and add to the quantity of oxygen, while animals reduce the quantity of oxygen and add to the quantity of carbon dioxide.

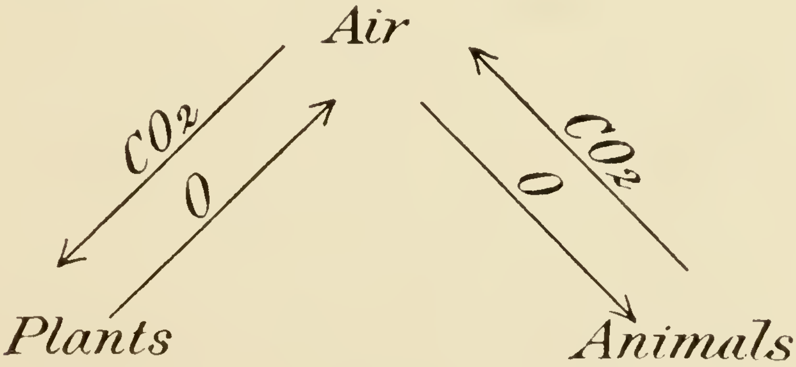

Fig. 8.

11. **Biological Importance of Water.**—We have already learnt in the earlier course ("Elem. Physiog.," Sec. 1, chap. xiv.) that water is a chemical compound of hydrogen and oxygen having the formula H_2O, and that it exists at

the ordinary temperature of the air as a liquid. Above 100° C. or 212° F. it becomes an invisible vapour, and below 0° C. (32° F.) it becomes solid. Among its important physical properties is its power of dissolving certain solids, the amount dissolved usually increasing as the temperature increases. We also know that water is able to hold in solution a small quantity of two gases of the atmosphere—carbon dioxide and oxygen.

To all living beings, whether plants or animals, water is of prime importance, for it is an essential constituent of all protoplasm or living substance—as essential as the proteids and mineral salts. It forms in most cases more than three-fourths the weight of the organism. Besides the water of organization in the protoplasm, water is absolutely necessary to plants for two other purposes. Plants feed, in part, on certain soluble mineral salts contained in the soil, and these can only be taken in at the roots. They are then carried to various growing parts of the plant in solution in the water. There is in the daytime a constant stream of water absorbed at the roots, passing upwards to the leaves, where much of this water of transport passes off into the air, as will be explained later (par. 49).

But the water absorbed is also used to some extent by plants in the building up of the molecules of sugar, starch, albumen, and other compounds forming their materials. From this point of view water is a food for plants, its molecules being incorporated in the constructive material constituting the plant body. Without water there could be no growth. Finally, water keeps the fresh green parts of plants in an extended stiff condition, as is shown by the fading and wilting of plants deprived of water (see par. 45).

For animals water is also of prime importance, for it not only constitutes a large proportion of the protoplasm of their tissues, thus serving as a food, but it also acts as a food-carrier, and as it is continually passing off the body in one form or other, it must be frequently renewed. It is of the greatest importance in the processes of digestion and assimilation, for until food is rendered soluble it cannot be absorbed into the blood, and without water there could be no transport of food materials to the various parts of the body. By means of perspiration water carries off a small amount of waste material, as well as the superfluous heat produced. It is, in fact, through water that the heat of the body is regulated. Lastly, water gives to the tissues and limbs of animals a certain amount of pliancy, so that they may bend and move easily (see par. 112).

12. **Starch.**—Starch is an organic substance or carbon compound formed by plants, and often stored as reserve food in seeds, roots, or stems. It forms a considerable part of the food of many animals, and the food value to man of many vegetable products largely depends on the amount of starch they contain. As we shall explain later (par. 52), an important function of green leaves is to decompose the carbon

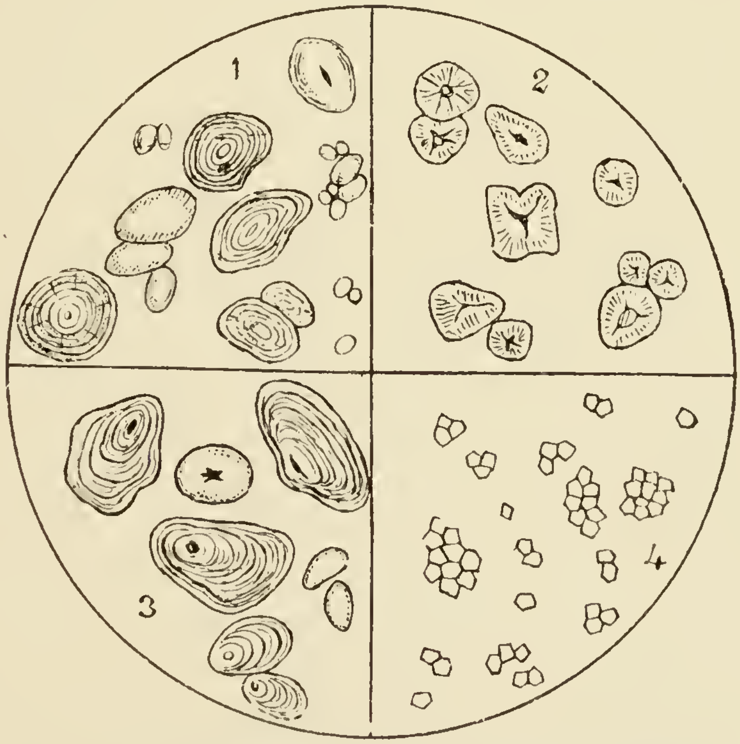

FIG. 9.—Varieties of starch-grains, highly magnified.
1, wheat ; 2, maize ; 3, potato ; 4, rice.

dioxide of the air by the aid of sunlight, and to use the carbon thus obtained in building up the compound termed starch. The chemical formula of starch is $C_6H_{10}O_5$, or some multiple of this: *i.e.* it consists of the elements carbon, hydrogen, and oxygen, the two latter elements being in the same proportion as they are in water. Sugar, gum, and cellulose have also this elementary composition, so that starch, sugar, gum, and cellulose belong to a class of compounds called **carbohydrates.** They are essentially different from the organic substances that contain nitrogen.

Starch can readily be obtained from wheat, maize, rice, potatoes, etc., and it appears as an opaque glistening white powder, without smell and almost without taste. When examined under the microscope, the starch is found to consist of very small solid grains, having a definite shape and structure in each species of plant. The starch-granules of wheat are nearly spherical, about $\frac{1}{400}$ inch in diameter on the average, and are made up of concentric layers in a membrane around a central nucleus. The starch-granules from the potato are oval, rather larger than those of wheat, with stratified layers around a nucleus near one end. The granules of maize show a radiating structure, while those of rice are very small and polygonal in shape. It is thus possible, by means of the microscope, to distinguish the starches from different plants by the size and form of the grains.

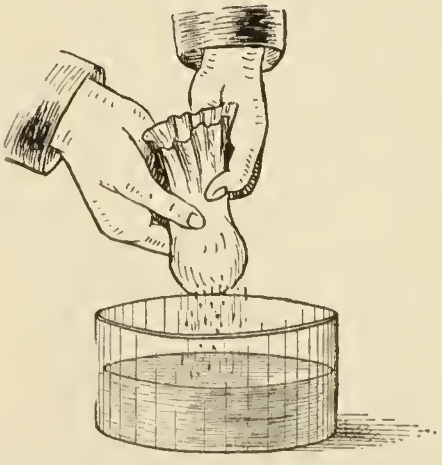
FIG. 10.—Method of obtaining the starch out of wheat flour when mixed with water and kneaded in a muslin bag.

Experiment. — To obtain starch from wheat, mix some wheat flour with cold water to a stiff dough, and then tie up the dough in fine muslin. Knead the dough in the muslin bag over a basin of water, dipping the bag in the water occasionally. The starch-granules come through the meshes of the muslin and form a milky fluid in the basin. On allowing the milky fluid to stand for some time, a sediment of starch-granules settles down. The water may then be poured off, and the starch collected on filter-paper and allowed to dry.

The grey sticky substance left in the bag after washing out the starch is for the most part a nitrogenous organic compound called **gluten.**

Starch may be obtained from grated potato pulp in the same way as from flour. Note the difference between the granules of starch from wheat flour and from potatoes.

All the varieties of starch have many similar properties. In the first place, **starch is insoluble in cold water.** If heated with water, however, the granules swell and the external membranes burst. The contents of the granules, but not the membranes, pass into a kind of solution. Such a solution of starch in hot water forms, on cooling, a gelatinous mass called **starch paste.** The irregular blocks or prisms of starch sold for stiffening linen arise from the cracking up of a cake of dried starch paste.

All kinds of starch have the property of being coloured a deep blue by the element iodine. This property forms a very useful test for the presence of starch. A solution of iodine can be made by dissolving a few crystals in alcohol or in potassium iodide solution. The iodine crystals will not dissolve in water.

Experiment.—Add a drop or two of iodine solution to some solid starch. Note the deep blue colour produced, almost black. Add a drop or two to the cut surface of a potato, a softened bean, or a piece of bread, and note the blue colour indicative of starch in these substances.

Experiment.—Put some powdered starch into a test-tube or small beaker containing cold water. Shake well and filter. Add a drop or two of iodine solution to the filtrate. There is no coloration, showing that no starch has dissolved in the cold water.

Experiment.—Put a little powdered starch into a test-tube or beaker of cold water, and then heat the water to boiling. Filter, and allow the filtrate to cool. When cool, add a drop or two of iodine solution, when a deep blue colour appears, proving that the hot water dissolved some starch. The colour disappears on heating, but reappears on cooling again.

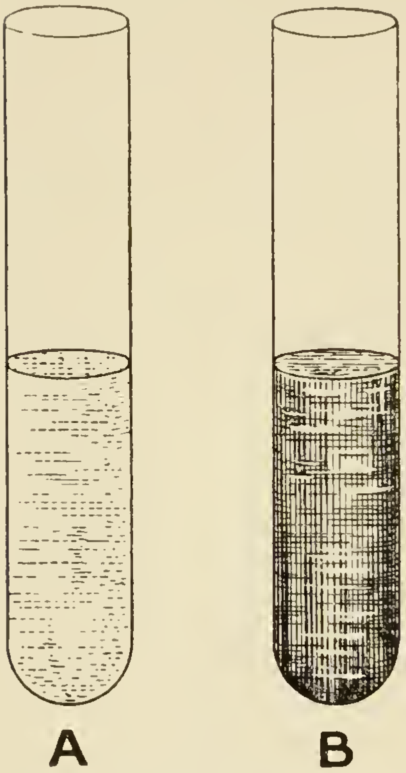

Fig. 11.—A, solution of starch; B, the solution turned dark blue by iodine.

When starch is *strongly* heated in a closed tube, it gives off water and acid vapours, leaving a residue of black carbon (par. 6).

When starch is *gradually* heated to about 160° C., it becomes converted into a soluble substance called **dextrine**, or British gum. This change is assisted by the addition of a little dilute hydrochloric or sulphuric acid. Prolonged heating of starch with dilute acid causes it to combine with water and to form a kind of **sugar** termed **glucose**, or "grape-sugar."

Experiment.—Prepare some starch paste, and add to it with constant stirring about a hundredth part of dilute sulphuric acid. Place in a flask and heat to boiling. Continue the boiling for ten minutes. Allow to cool, and then test with iodine solution. There is no coloration, for the starch by taking up the elements of water has been turned into the variety of sugar called glucose.

$$\underset{\text{Starch.}}{C_6H_{10}O_5} + \underset{\text{Water.}}{H_2O} = \underset{\text{Glucose.}}{C_6H_{12}O_6}$$

The conversion of insoluble starch into glucose or grape-sugar is a matter of great importance both in nature and in certain arts.

In green leaves exposed to light and supplied with carbon dioxide and water, sugar and starch are produced, the starch accumulating during the day as minute granules in the leaf-cells. The plant uses the starch so formed to assist in manufacturing the living substance termed protoplasm, as well as to form a store of nourishment when transferred to its seeds and other parts. Now, the granules first formed in the leaf-cells are in a solid condition, and before this starch can be assimilated with the food substances taken in by the roots from the soil to form protoplasm, or before it can be transferred to other parts, it must be rendered soluble. This is effected by the agency of a particular juice known as a **ferment,** which has the power of changing the insoluble starch into a soluble sugar, when transference to another part of the plant can be effected. The starch formed in the leaves during the day is thus carried away during the night to other parts (see par. 20). During the process of germination, the starch stored in a seed is turned into soluble sugar by the same ferment, and is thus made available for the nourishment of the young plant.

Starch forms a large part of the food of man and some other animals. Three-fifths of wheaten flour is starch, and it forms the main part of rice, maize, and potato. Sago and arrowroot are almost pure starch. But before starch can be absorbed into the blood of the digestive canal of an animal, it must undergo some change. During mastication of the food the starch portion is acted on by a ferment in the saliva, which changes it into the same soluble sugar as exists in plants. It is then capable of being taken up by the blood.

13. Cellulose.—Closely allied to starch, and having the same elementary composition, $C_6H_{10}O_5$, but different properties, is the white solid called **cellulose.** It is the essential constituent of the walls of vegetable cells, whether thin or thickened, and it forms the fibrous framework of all plants, as well as the envelope round starch-grains. Cotton-wool, flax, and hemp consist of cellulose mixed with small quantities of mineral matter, while woody fibre is modified cellulose with colouring and mineral matter. Cellulose is indigestible, and insoluble in water and all ordinary solvents, but is remarkable for the amount of water that it will absorb. Bodies composed of cellulose turn blue with iodine only after having been heated with strong sulphuric acid.

14. Sugar.—Sugar is an organic substance formed by many plants. It belongs, like starch, to the class of compounds called *carbohydrates*, as it consists of carbon, hydrogen, and oxygen, with the last two elements in the same proportion as in water (two atoms of hydrogen to one atom of oxygen). The proportion of carbon, however, to the elements of water is not the same as in starch and cellulose.

The chemist recognizes several varieties of sugar, which differ somewhat in chemical composition and physical properties. The two chief kinds are **saccharose** or cane-sugar, and **glucose** or grape-sugar. **Lactose** or milk-sugar, occurring in milk, and **maltose**, formed during the fermentation of malt, are sugars that belong to the saccharose kind. Saccharose or cane-sugar ($C_{12}H_{22}O_{11}$) is the crystallizable sugar obtained from the sugar-cane, the beet-root, and the sugar-maple, for the sugar from all these is chemically the same. Saccharose is also contained in several fruits, where it is mixed with grape-sugar and starch. It is the sweetest of the sugars and the most soluble in water, a pound of cold water dissolving about three pounds of cane-sugar. On heating the water, more sugar still may be dissolved. If threads be suspended in a hot saturated solution, and the solution be then allowed to cool slowly, prismatic crystals of sugar candy will form on the threads.

Experiment.—Take some loaf-sugar, which is nearly pure cane-sugar, and heat it on iron or tinplate. Note the fumes given off and the well-known smell of burnt sugar. On further heating, we find only a black residue of carbon.

Glucose or grape-sugar ($C_6H_{12}O_6$) occurs very widely in the cell-sap of many vegetables, especially in the juice of the grape, cherry, pear, and other sweet fruits. It is also found in honey. Glucose is less sweet than cane-sugar, as may be found by comparing the taste of two or three granular masses from a raisin (a dried grape) with two or three similar pieces of common sugar. It is also less soluble than common sugar. Glucose is further distinguished from cane-sugar by the fact that under the influence of yeast it readily ferments, yielding mainly alcohol and carbon dioxide.[1] Cane-sugar does not directly ferment with yeast.

Glucose is now prepared artificially in large quantities for the use of brewers and confectioners by the action of sulphuric acid on grains that contain a large proportion of starch. As it is difficult to crystallize, commercial glucose is in the form of a syrup or pasty mass.

Sugar is formed by plants from the food materials taken in, and it is afterwards used in the construction of protoplasm, or transferred from one part of the plant to the other to be kept as reserve food. It is stored either as sugar or after being converted into starch. During the growing summer season sugar is transported from leaves to roots in many plants, and then from roots to stem and leaves when growth begins again in spring after the winter's rest. The sugar of plants in the form of nectar also serves to attract insects (par. 62). Sugar is largely used as food by man, the supply being chiefly obtained from the beet-root, the sugar-cane, and the sugar-maple. As already stated, all these give saccharose or cane-sugar. The special value of sugar as a food is due to the fact that it is, after slight change, readily and directly absorbed into the blood in the alimentary canal, and thus becomes a nutritive substance at once.

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[1] Another distinguishing test for grape-sugar is described on page 237.

CHAPTER III.

THE GENERAL BUILD OF A FLOWERING PLANT, WITH A DESCRIPTION OF THE PARTS OF A FLOWER.

15. A Flowering Plant.—An ordinary flowering plant, such as the wallflower, the stock, the bean plant, or the laburnum, possesses distinct parts known as the root, stem, leaves, and flowers. The root and stem form a central **axis**, and it is the ascending portion of this axis that is the **stem**, while the descending portion of the axis forms the main **root**. Generally, but not always, the root is buried in the soil, and the stem is above ground. Roots have various forms. In many cases, as shown in Fig. 12, there is a main root or **tap-root**, which gives off branches from above downwards, and becomes thinner as it penetrates deeper into the earth. The chief functions of the root are to fix the plant in the soil and to absorb nutriment (par. 45). Roots also often act as storehouses of food.

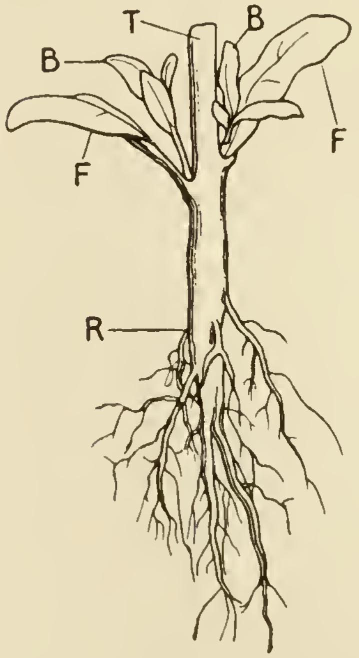

FIG. 12.—Root and lower portion of stem of wallflower. R, root; above R, lower portion of stem T; F, foliage leaves; B, buds.

The stem possesses the power of giving off lateral expansions from its sides called leaves, and at its tip the leaves are crowded together around a growing point to form a **bud.** A root has no leaves, and does not terminate in a bud, but has a root-cap covering a growing point, as is explained later (par. 32).

The point at which leaves arise on a stem is usually thickened, and is termed a **node,** and the interval between two successive nodes is called an **internode.** The angle between leaf and stem is called an **axil** (Lat. *axilla*, "an armpit"), and it should be observed that a bud often arises from an axil just above the insertion of the leaf, and that such a leaf-bud often becomes a branch or secondary axis. The larger divisions of a stem are known as **branches,** and the smallest **twigs,** and these divisions, like the main stem, may develop leaves and buds in their turn (Quest. 10, p. 270).

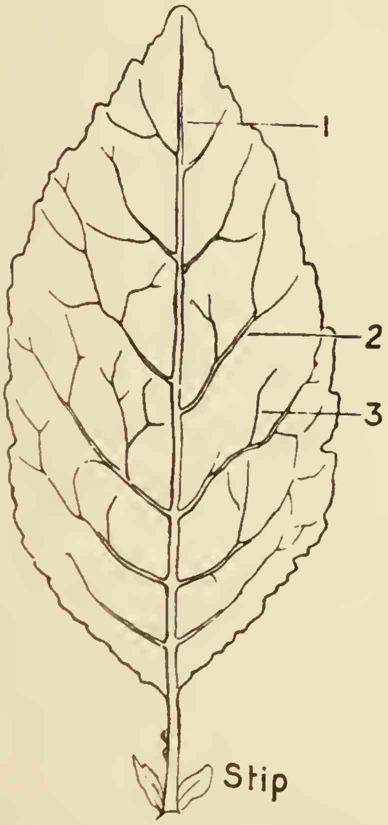

FIG. 13.—Cherry leaf. Stip, small stipules at base of leaf-stalk; 1, midrib; 2 and 3, veins from midrib.

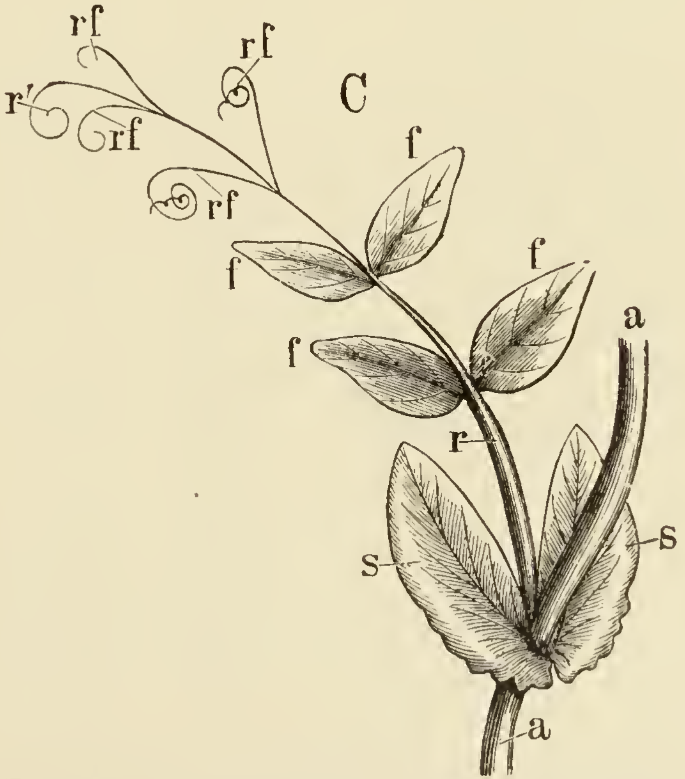

FIG. 14.—Leaf of a Pea. a, stem; s, s, stipules; r, rachis, or leaf-stalk; f, f, leaflets; rf, rf, upper leaflets, represented by tendrils; r′, end of the rachis, also represented by a tendril.

Leaves are lateral appendages of a stem or branch arising from a surface layer of the substance of the stem. They vary greatly in form, and are capable of many modifications and adaptations. The edges of the blade may be entire or indented in various ways, while the surface may be smooth or covered with hairs or down. The youngest leaves are always nearest the apex of a stem or branch, and the oldest nearest the base. New leaves never originate below those already formed.

A fully developed leaf consists of two chief parts—a leaf-stalk of hard substance called the **petiole**, and an expanded portion on each side of a midrib called the **blade** or **lamina**. The midrib is continuous with the petiole or leaf-stalk, and gives off branches on each side called **veins**, these veins subdividing again and again. Between the veins of hard substance lies the softer tissue making up the bulk of the leaf-blade. At the base of the leaf-stalk there are often found two leaf-like appendages on each side called **stipules**.

The mode in which the veins of a leaf are arranged is termed the **venation**. In Dicotyledons (par. 29) the veins are much branched and form a regular network, so that such leaves are said to be **net-veined** or **reticulate** (Lat. *rete*, "a net").

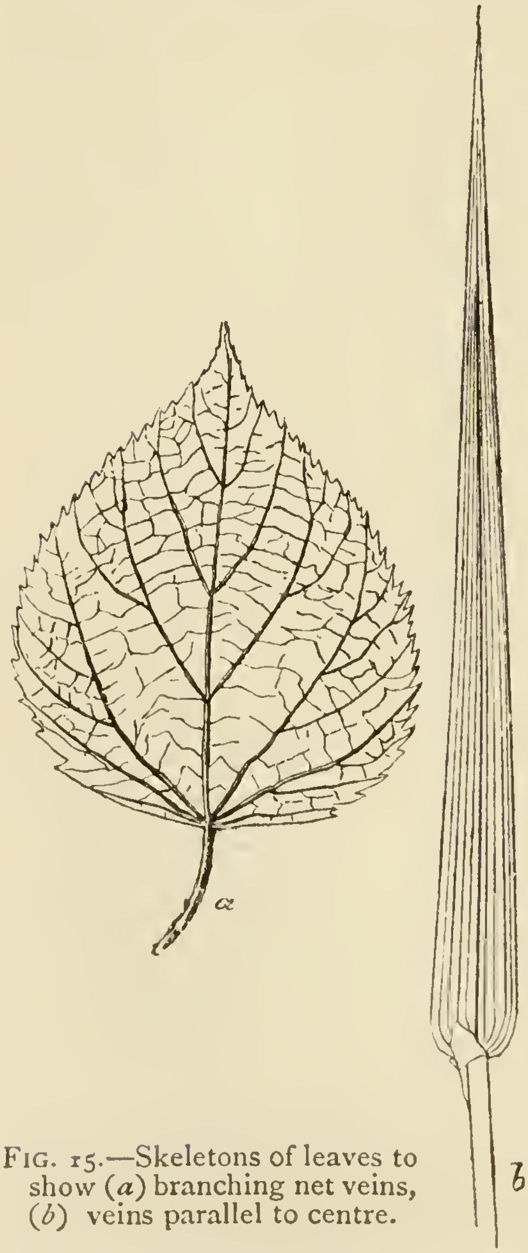

Fig. 15.—Skeletons of leaves to show (*a*) branching net veins, (*b*) veins parallel to centre.

In most Monocotyledons the veins are more or less parallel, and they are said to be **parallel-veined**. When leaves decay, the harder tissue of the veins remains after the soft part has disappeared, leaving a skeleton outline of the leaf. In most cases the chief veins and veinlets may be well seen on holding the leaf up to the light.

Some leaves give rise to cord-like climbing organs called **tendrils.** Thus the terminal leaflet of the compound leaf of the pea gives rise to a tendril, which often gives off branch tendrils (Fig. 14).

Some leaves have no leaf-stalk or petiole, but spring directly from the stem. They are then said to be **sessile.**

The coloured leaves that are arranged in circles or whorls at the end of certain branches of the stem form the **flower.** As the flower gives rise to the **fruit**, and is therefore the **organ of reproduction**, it will be well to get a clear idea of its main parts at once, using some simple regular flower for an illustration.

16. The Parts of a Flower.—A complete flower in the most fully developed plants consists of a stem, bearing above four successive circles or whorls of variously modified leaves. The flower-stalk is called the **peduncle** or **pedicil,** and the leaves forming the flower are crowded together at its upper swollen end, which is termed the **receptacle.** Passing from the outside of the flower inward, the four whorls of modified leaves are thus named:

1. Calyx,	composed of	sepals	These form the **perianth,** or floral envelope.
2. Corolla	„	petals	
3. Androecium	„	stamens	These are the essential parts of the flower.
4. Pistil	„	carpels	

When the leaves composing a whorl are alike, the flower is said to be **regular**; when the leaves of a whorl vary, the flower is said to be **irregular.** Generally, but not always, the parts of adjoining whorls alternate, so that a petal comes between two sepals, and a stamen comes between two petals. The calyx and corolla are mainly protective in function.

The essential reproductive organs are the stamens (the male reproductive organs), collectively termed the **andrœcium,** and the carpels (the female reproductive organs), collectively termed the **gynœcium** or **pistil.**

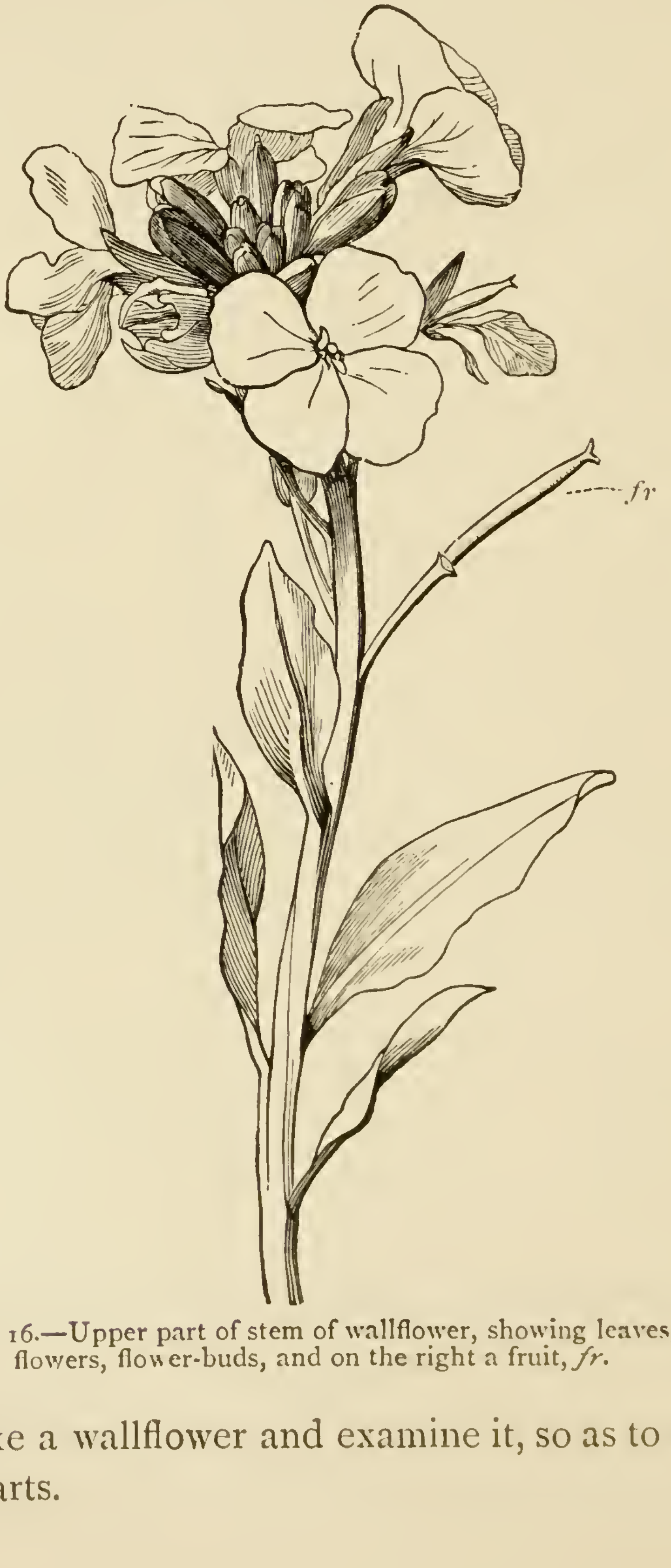

Fig. 16.—Upper part of stem of wallflower, showing leaves, flowers, flower-buds, and on the right a fruit, *fr*.

Let us take a wallflower and examine it, so as to recognize the above parts.

The outer or lower whorl is the calyx (Figs. 17 and 18). It consists of four darkish leaves (the sepals), each separate from the other. If we pull off the sepals of the calyx, we come to the next whorl that forms the corolla, and this whorl consists of the petals —four separate brown leaves (often streaked with orange). A petal of the corolla in the wallflower has its blade (L) borne on a small stalk (O) called its claw (Fig. 19). On stripping off the petals of the corolla, we find a whorl within the corolla, which consists of six stamens (collectively called the andrœcium), four long and two short. Each stamen has a stalk called its **filament,** and a head or case called the **anther** (Fig. 20). The anther usually consists of two lobes, united together and to the filament by a part called the **connective.** The anther lobes contain a fine powder or dust called the **pollen,** and as the anther lobes open at a certain period, the pollen grains are thus allowed to escape. Falling on or carried to the central part of the flower called the **pistil,** the pollen from the stamens assists in forming the seeds within the pistil. On picking off the stamens of the wallflower, we find in the centre the **pistil** still left on the receptacle. It is a rather cylindrical hollow body tapering towards the top, where it terminates in a small fork. The lower thicker part of the pistil is called the **ovary,** and contains small bodies called **ovules,** which are destined, after being fertilized by pollen from anthers, to become seeds which will reproduce the plant. The top of the pistil is called the **stigma,** and the short neck connecting the ovary and the stigma is the **style** (Figs. 23 and 27). In many plants the style is much longer than in the wallflower. The pistil in the wallflower is really composed of two modified leaves called **carpels,** arranged so as to form a kind of pod separated into two compartments by a partition (Figs. 22 and 24).

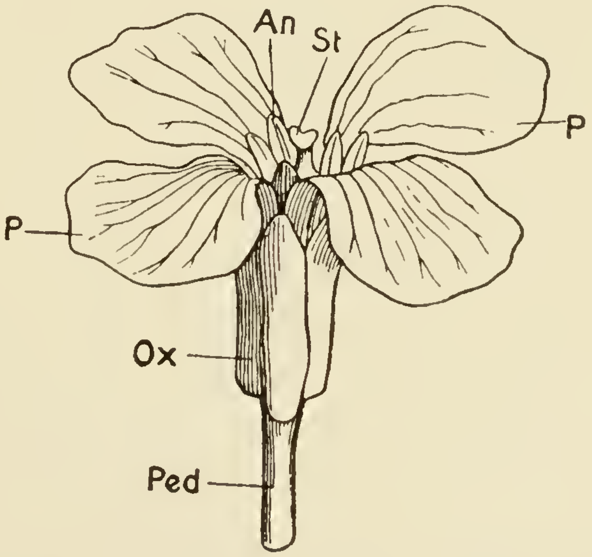

Fig. 17.—Wallflower. Ped, peduncle, or flower-stalk; Ox, calyx ; P, petal of corolla ; An, anther of stamen ; St, stigma of pistil.

The ovules in the ovary are the young unripe seeds, or rather the structures from which the seeds arise. In order that they may become true seeds capable of producing young plants, the ovules must first be fertilized by pollen, either from the same flower or from some other flower. The **fruit** of the wallflower, as of other flowering plants, is the ripened pistil, and the seeds are the ripened ovules. During the process of ripening the pistil of most flowers increases in size, and important changes occur in the ovules, while the calyx, corolla, and stamens usually wither and fall off. When fully ripe the fruit, which is a kind of long pod in the wallflower, opens, as shown in Fig. 24, and the seeds fall out.

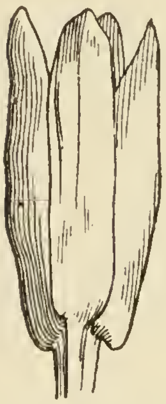

Fig. 18.—Calyx of wallflower detached.

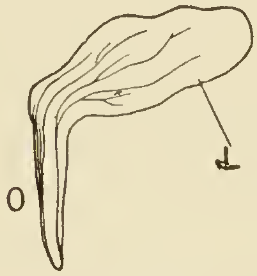

Fig. 19.—One petal of corolla of wallflower. L, blade; O, claw.

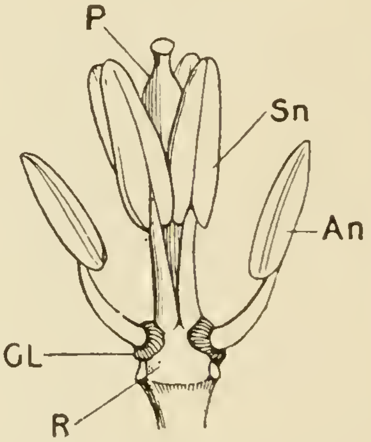

Fig. 20.—Wallflower after removal of calyx and corolla. R, receptacle; Gl, honey glands at base of stamens, Sn; An, anther of stamen; P, pistil.

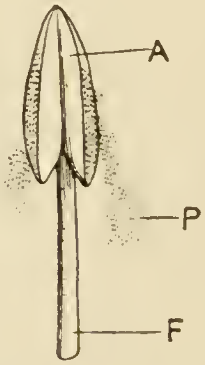

Fig. 21.—A single stamen. F, filament; A, anther; P, pollen escaping from anther.

From our study of the flower of the wallflower plant we have learnt the names and functions of the chief parts of a flower. On examining other flowers, the reader will soon learn that there are great variations in the shape, mode of attachment, and position of the sepals, petals, and stamens as well as in the carpels that form the pistil. Take, for example, a buttercup and carefully dissect it. Note that the calyx is composed of five distinct greenish-yellow sepals; that the corolla consists of five golden-yellow separate petals; that the andrœcium consists of numerous separate stamens; and that the pistil consists of numerous distinct carpels. Cut open one of the carpels, and notice that the one-celled ovary contains only one ovule, and that the very short style is capped by a curved stigma. The fruit or ripe pistil at a later period, or on an older plant, will be found to consist of a cluster of these ripened carpels, each containing one seed (Fig. 25).

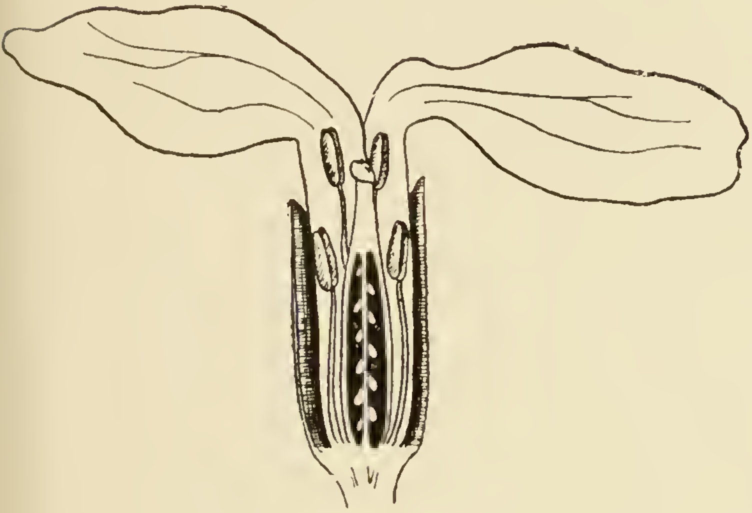

FIG. 22.—Vertical section of flower of wallflower, showing ovules within the ovary of the pistil. (From Aitken's "Elementary Text-book of Botany.")

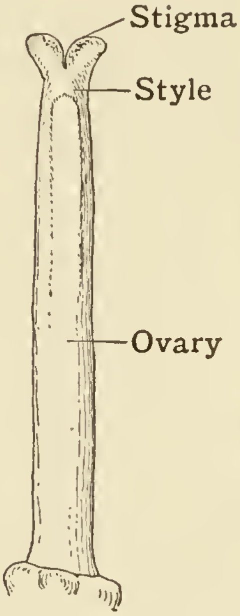

FIG. 23.—Pistil of wallflower.

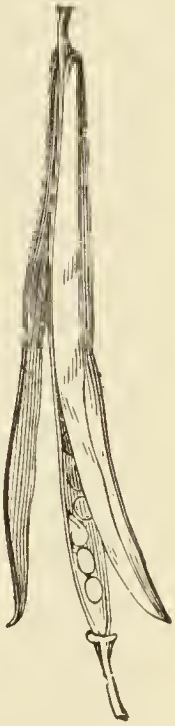

FIG. 24.—Ripe fruit of wallflower, showing seeds.

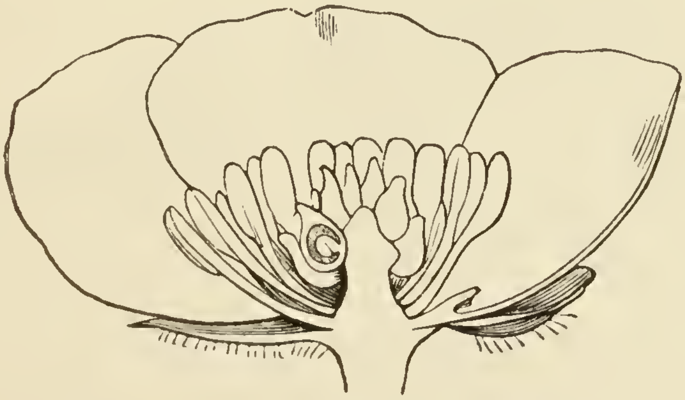

FIG. 25.—Longitudinal section through the flower of buttercup, showing the calyx, corolla, stamens, and carpels, one carpel being cut through to show the ovule within.

As examples of other flowers, the parts of which may be easily recognized, the reader should examine the blossom of the cherry or apple, a primrose, and the flower of the blackberry. He will thus begin to get some idea of the great variation of form of the same external organ in different plants. All these flowers are said to be **regular**, as the calyx and corolla consist of equal and similar leaves. When the parts of the calyx or corolla are of different shape, as in the bean flower, the pansy, and the dead nettle, the flower is said to be **irregular.** A **complete** flower is one that has all the four floral whorls; an **incomplete** flower is one that does not possess all the floral whorls.

The word **perianth** is used to indicate the parts outside the stamens and pistil. Flowers that have both sepals and petals are then said to have a double perianth, but when either calyx or corolla is absent there is only a single perianth. This is the case with the tulip, which has a perianth with six regular pieces. This is also the case with the narcissus lily, or daffodil, but in it there is also a cup adherent to the leaves of the perianth, and rising like a crown in the centre of the flower. This cup is called the **corona**, and must not be mistaken for a corolla. Count the number of stamens in

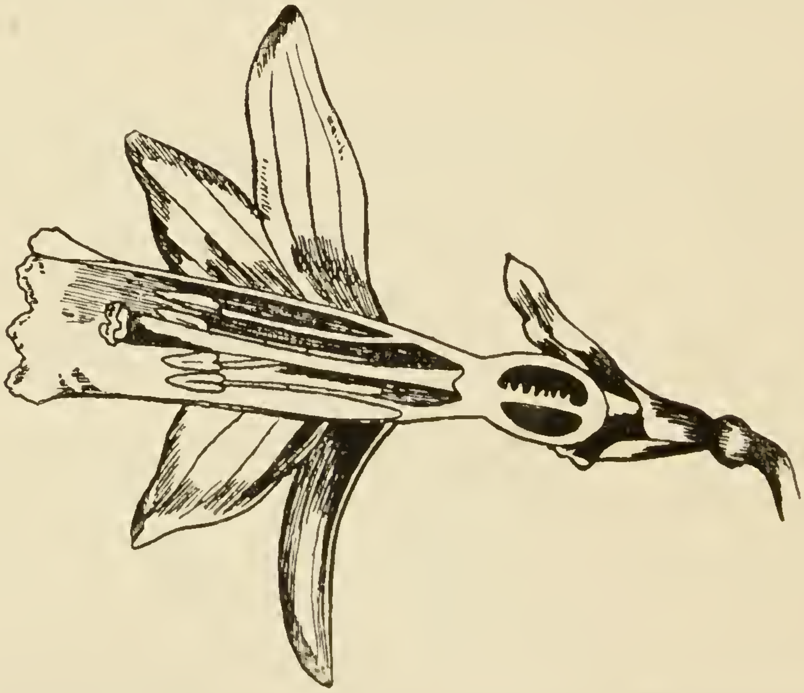

FIG. 26.—Vertical section of flower of daffodil. (From Aitkin's "Elementary Text-book of Botany.")

these two flowers, and note the form and internal structure of the pistil. The tulip will be found to have six stamens springing from the receptacle, and placed opposite the pieces of the perianth. The daffodil has also six stamens, but they are attached to the tube of the perianth. In both cases the pistil will be found to consist of three carpels united into a three-celled ovary with one style, but the stigma in the tulip is trifid, or three-lobed, while in the daffodil it forms a knob.

17. The Pistil and Fruit.—So important is the part played by the central organ of the flower, the pistil, in the reproduction of a plant, that it will be well for the reader to consider it still further. As already stated, the pistil consists of one or more modified leaves called carpels. Imagine a leaf folded along its midrib so that its edges meet and unite to form a compartment, and we shall understand the simplest form of pistil. In a typical pistil like that found in the primrose or cherry flower, three parts can be noted: (1) the ovary containing the ovules; (2) the style; and (3) the stigma. (A pistil has been compared to a bottle, the lower part of which would correspond to the ovary, the neck to the style, and the cork to the stigma.) Within the ovary lies one or more ovules, attached to a part of the ovary called the **placenta**, the attachment being sometimes by a small stalk called the **funicle**, and sometimes without a stalk. The place of attachment of the ovule is termed the **hilum.** The main body of the ovule is a structure termed the **nucleus** or **nucellus**, which contains an **embryo sac** in which lies a germ-cell called the egg-cell, or **oosphere.** The nucellus possesses two coats or integuments, which have at one point a small opening called the **micropyle.** The fertilization of the ovules in the ovary is effected by means of pollen grains from the same or a like flower, that reach the stigma of the pistil in some way (see Chap. X.). The stigma, when in proper condition, is usually of a soft sticky nature, so as to cause the pollen grains to adhere. The pollen grain on the stigma then sends out a tube that passes through the style, and at last reaches the embryo sac of an ovule through the micropyle. The pollen tube carries down in its apex a nucleated mass of protoplasm, and this is passed over into the germinal vesicle or egg-cell of the embryo sac, the union of protoplasm from the pollen tube with the egg-cell of the ovule constituting the act of fertilization (Fig. 27). After fertilization the stigma and style, having performed their functions, usually wither, but the ovule thus fertilized by the pollen grain undergoes a series of remarkable changes that result in a ripe seed containing a young plantlet.

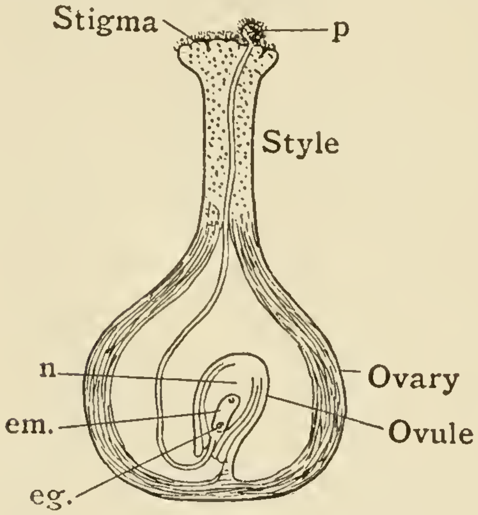

FIG. 27.—Diagram of a typical pistil with one ovule in the ovary. p, pollen grain on the stigma. The section also shows a pollen tube from a pollen grain passing through the style and the ovary and entering the micropyle of an inverted ovule; n, the nucellus; em, embryo sac; eg, egg cell.

The fruit is the part of the plant that contains the seeds. Whether it is good to eat or not makes no difference as to this part being the fruit. It consists of that part of a single flower that persists after fertilization until the seeds are ripe, and this is in many cases merely the ripened pistil and its ovary or ovaries. In some cases, however, a part of the calyx or a part of the receptacle of the flower-stalk is included in the fruit. The seeds are the fertilized and ripened ovules. Fruits are of various forms, and some of these are described later.

18. Summary of Flower.—As a useful summary of the chief points connected with the structure and function of flowers, the annexed figure of a typical flower in vertical section may be carefully studied along with the verbal statements added.

Starting from the centre and passing outwards, we find the following parts in every complete flower: (1) In the centre is the **pistil**, consisting of one or more carpels, and usually separable into an **ovary** below containing one or more **ovules**, a **style** and a **stigma** above. The pistil is the female part of the flower, and when duly fertilized and ripened it becomes the fruit, its ovules being then changed into seeds.

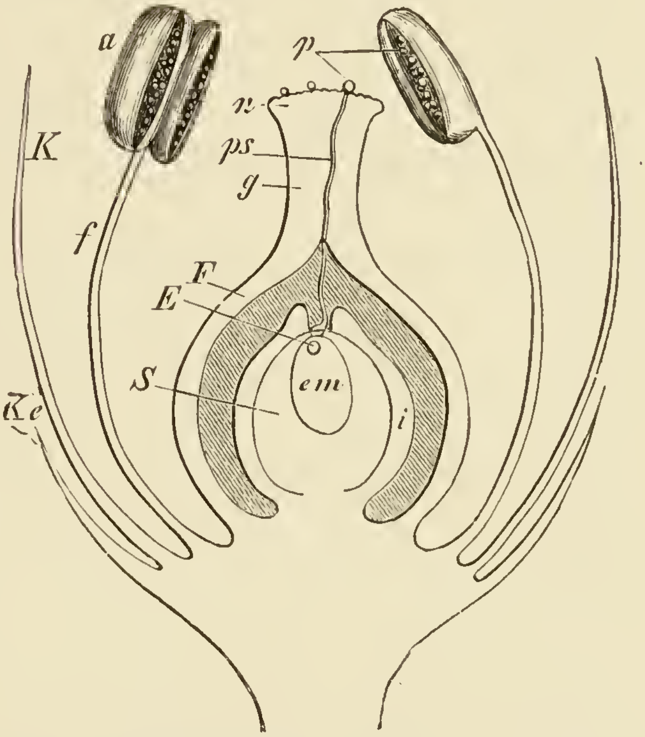

Fig. 28.—Diagrammatic section of a flower. *Ke*, calyx ; *K*, corolla ; *f*, filament of stamen ; *a*, anther, showing the pollen-sacs open, and the pollen-grains, *p*, escaping. The central part or the gynœcium shows the ovary, *F*, style, *g*, and stigma, *n*, on which are pollen-grains, one sending down a pollen-tube, *ps*, to the micropyle of the ovule. The central structure in the ovary is the ovule, showing the integument, *i*, the nucleus, *S*, and the embryo-sac, *em*, with the egg-cell or germinal vesicle, *E*, at the apex, close to the end of the pollen-tube. (After Prantl.)

(2) Outside the pistil come the male parts of the flower, called the **stamens**, each stamen consisting of a stalk or filament, and of two small pollen bags called **anthers**. The grains of pollen from the anthers fall or are carried in some way to the stigma of a pistil, and, being held there by a sticky secretion, send down a pollen-tube that carries a fertilizing cell to a special part of an ovule. Ovules so fertilized develop into seeds, while unfertilized ovules wither away.

(3) Outside the stamen comes a set of bright-coloured leaves called individually **petals**, but collectively the **corolla**. Sometimes the corolla consists of separate distinct petals, sometimes they are partially united, and sometimes they are entirely united into a single tube, as in the foxglove. And—

(4) Outside the corolla comes a set of leaves termed singly

sepals, but collectively the **calyx**. The calyx, like the corolla, may consist of separate parts or be more or less united.

The floral envelopes, as the corolla and calyx are called, form the conspicuous parts of a flower, and are the parts usually meant when people talk of a flower. But, as already shown, they are not the important and essential parts, though they have several uses. They serve to cover up and protect the flower in the bud, and the bright corolla serves to attract insects to a flower in search of honey, and this leads them to carry pollen grain from plant to plant. This is an advantage to plants, for it is better for a flower to receive pollen from another flower of its own kind than to fertilize itself by letting its pollen fall upon its own pistil. We shall again take up this subject of fertilization in a later chapter.

18a. Duration of Plant Life.—With reference to the total duration of life, plants are divided into **annuals**, **biennials**, and **perennials**.

An **annual** is a plant which passes through its whole life-history in one year or one growing season. Starting from a seed in spring, it develops root, stem, leaves, and flowers, and then perfects its fruit with the contained seeds within the course of a year. The plant itself then dies.

Biennials are plants which require two seasons of growth before producing flowers and seeds. During the first year they develop root, stem, and leaves, and then, after a winter's rest, continue growth and also produce flowers and fruit. At the end of the second season, when the seeds are ripe, the plant dies.

Annuals and biennials have much soft substance and but little woody matter in their stems, and are said to be **herbaceous** plants in contradistinction to plants that have a woody stem.

Perennials are plants which live more than two years, and which usually require several years before producing flowers and fruit. After having once produced seeds, the flowering and fruiting may continue year after year for a considerable period. All the hardy shrubs and trees are perennials. Many of them produce woody stems of great thickness and strength.

CHAPTER IV.

THE MINUTE STRUCTURE OF PLANTS, CELLS, AND TISSUES.

19. Vegetable Cells.—The simplest plants with which we are acquainted consist of a single minute bag or sac enclosing a slimy mass of granular protoplasm, near the centre of which is a denser mass called the **nucleus**. Such a distinct nucleated mass of protoplasm is called a **cell.** Other plants at the beginning of their life consist at first of a single cell, which divides and subdivides, until by repeated growth, subdivision, and modification the body of the plant consists of a mass of cells, and of minute fibres and vessels derived from cells. Microscopic examination, therefore, of very thin slices made in several directions from the root, stem, leaves, or flowers of any higher plant, shows that every part of a plant is made up of a crowd of cells, or of elements that have been derived from cells. Some knowledge of the structure of cells and the other minute elements of plants is very helpful in understanding the mode of action and working of plants. Such knowledge can only be gained at first hand by the help of a microscope magnifying 100 or more diameters, for cells, although occasionally visible to the naked eye, like those forming the pulp of the fruit in the orange, are usually too small to be seen without such aid. Figures, however, will assist the reader when such help is not at hand.

A very young vegetable cell consists of a more or less rounded thin-walled sac filled with protoplasm (Fig. 29). Such cells vary in size from $\frac{1}{300}$ to $\frac{1}{1200}$ inch in diameter. They are capable of dividing so as to produce new cells. Cell-division always begins with and includes the nucleus (Fig. 29). As the cell grows, its wall increases faster than the protoplasm, thus causing spaces within called **vacuoles**, which usually become filled with a watery fluid called **cell-sap.** Cell-sap consists of water with various inorganic and organic substances in solution. The vacuoles increase in number and size, and may at last unite to form a central cavity with the protoplasm lining the cell wall. Such an older but still living cell is shown in Fig. 30, where a vacuole with cell-sap occupies the interior, and the protoplasm forms but a lining on the cell wall. The cell wall is formed of a solid transparent dead material called **cellulose**, which has been derived from the lining protoplasm of the interior.

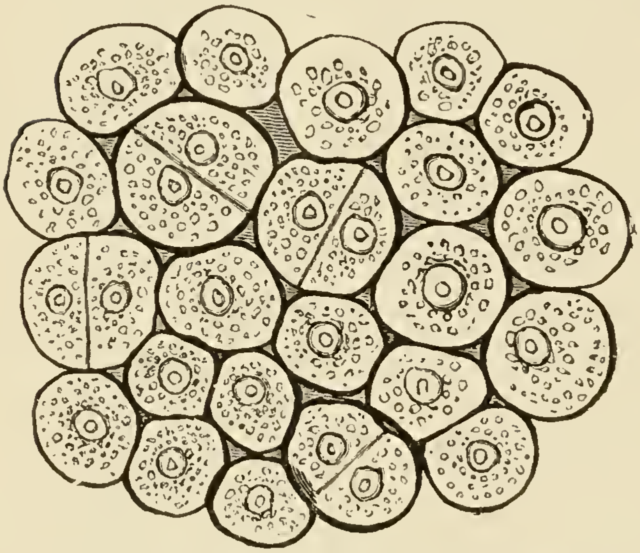

Fig. 29.—Transverse section through the growing point or primary parenchyma of the fig, showing nucleated cells; the cells are still roundish, and some in the act of dividing. (× 1200.)

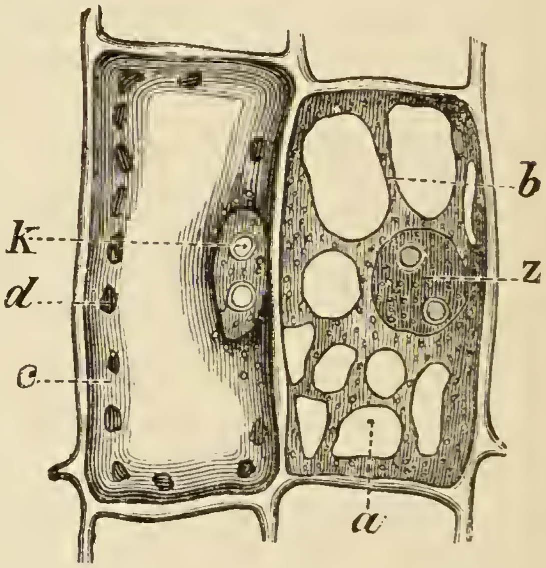

Fig. 30.—Two young cells, showing vacuoles, etc. *a*, vacuole; *b*, strand of protoplasm; *z*, nucleus; *k*, nucleolus; *d*, chlorophyll corpuscles; *c*, layer of protoplasm of cell wall. × 800. (Sorauer's "Physiology of Plants.")

20. Cell Contents.—The protoplasm of cells is formed from matter supplied by various important food substances taken in by the plant. Among the important substances contained in cells and manufactured by the protoplasm are granules of chlorophyll, starch, and aleurone, while various kinds of sugar remain in solution in the cell-sap.

Chlorophyll is the green colouring matter of plants, and is found in all the higher plants. It is contained in granules of protoplasm termed "chloroplasts." A chloroplast is thus a small granule of cell-protoplasm saturated with chlorophyll. The chlorophyll can be readily dissolved out of the granule with alcohol, leaving the colourless granule of protoplasm behind. Chlorophyll is only produced by cell-protoplasm under the influence of light. It is only found in those cells at or near the surface that are exposed to light. When kept in the dark the green parts of a plant become bleached, owing to the disappearance of the chlorophyll. In the autumn, before the leaves fall, the chlorophyll decomposes into red and yellow colouring matter, which gives rise to "autumn tints of leaves." Chlorophyll has an important part to play in the life of the plant, for with the energy supplied by light it is able to split up carbon dioxide from the atmosphere. The oxygen is given back to the air, but the carbon is made to unite with the elements of water to form a sugar, which is then turned into starch (par. 54).

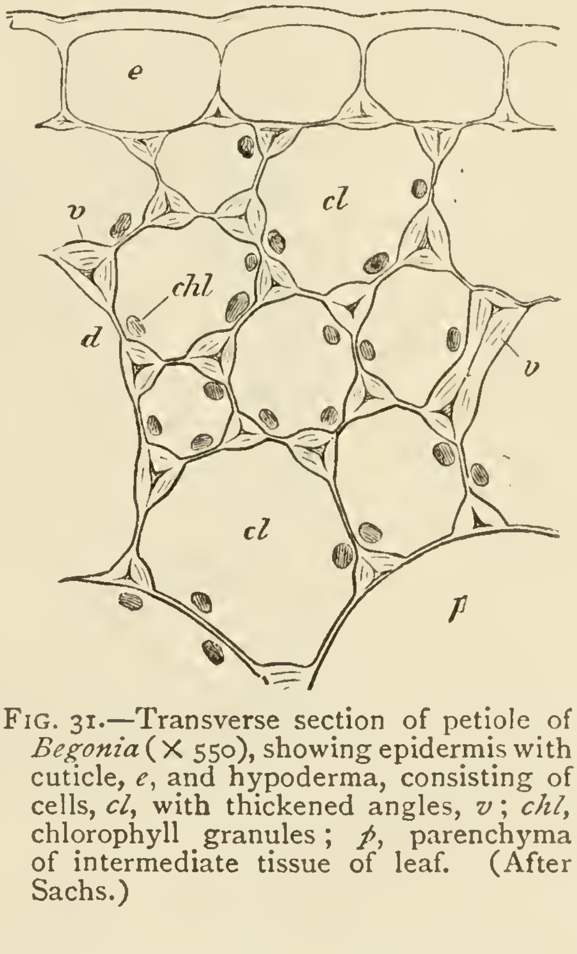

FIG. 31.—Transverse section of petiole of *Begonia* (× 550), showing epidermis with cuticle, *e*, and hypoderma, consisting of cells, *cl*, with thickened angles, *v*; *chl*, chlorophyll granules; *p*, parenchyma of intermediate tissue of leaf. (After Sachs.)

Starch, the composition and properties of which have been already examined (par. 12), occurs in plant-cells in the form of white granules of various sizes often marked with concentric rings. It exists in quantity in the potato and the various cereals, and is usually first formed by the chloroplasts in the leaf under the stimulus of light. The grains thus formed in the leaves are small, and are constantly being changed into sugar and carried away to form reserve food in the seeds and other parts of the plant, for the starch thus carried away in the form of sugar is either reconverted into starch by the action of leucoplasts (bodies allied to chloroplasts, but without chlorophyll), or it is stored as sugar dissolved in cell-sap.

Sugar is formed of the same elements as starch (par. 14), but differs from it in being soluble in the cell-sap. It abounds in some of the cells of the sugar-cane, maple, beet, and in many fruits.

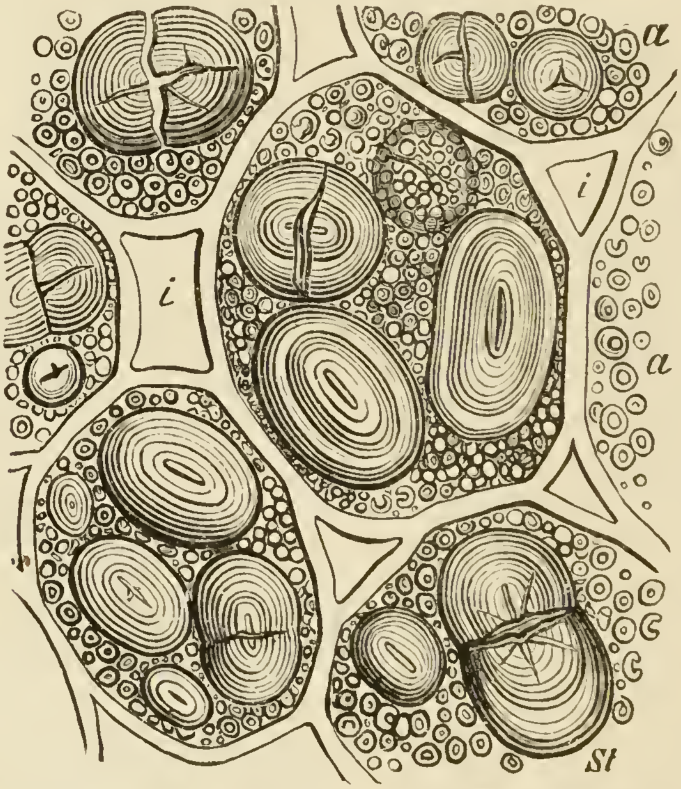

Fig. 32.—Cells of cotyledon of *Pisum sativum*, pea, showing *St*, starch-granules with central hilum and concentrated striæ; *a*, granules of aleurone; *i*, intercellular spaces highly magnified. (After Sachs.)

Aleurone is a proteid or nitrogenous substance found as granules or grains in certain seeds. It is probably a reserve food material.

Beside the cell contents already mentioned, crystals of calcium oxalate occur in the vacuoles of many cells. Drops of oil are also elaborated by many plants, and occur in the cells of the seeds of the flax plant (linseed), the olive, the castor-oil plant, etc.

Remarkable compounds called **alkaloids** also occur in the cells of certain plants. Morphia, quinine, and theine belong to this class of substances.

21. Shape of Cells.—Young cells have a more or less globular or rectangular form (Fig. 29), but many of these cells, as they become older, undergo considerable changes both of form and structure. Thus we find polygonal cells, star-shaped cells, flat cells, etc. Again, the uniformly thin cell wall of young cells is composed of cellulose, and this outer membrane often becomes thickened internally, either uniformly all over or only in certain parts. The thickening consists of depositions of successive layers of some form of cellulose. When the thickening of the cell wall takes place all over, except in small spots, these thin spots sometimes appear as pits, and such cells are called **pitted cells.** Such a cell with its pits forming canals is seen in section in Fig. 33. In some cases the thickening on the cell wall only occurs in bars, or circles, or lines. When the thickening of the cell wall is deposited in bars, forming an irregular network, we get **reticulated** cells; when as a separate ring, we find what are called **annular** cells; and

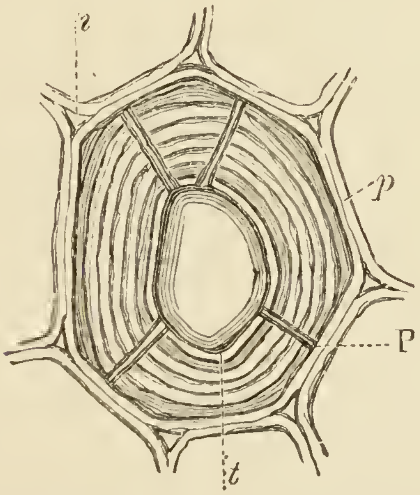

Fig. 33.—Transverse section of a cell with thickened wall. *p*, primary cell wall; *t*, innermost thickening layer; P, pore-canal; intercellular space highly magnified.

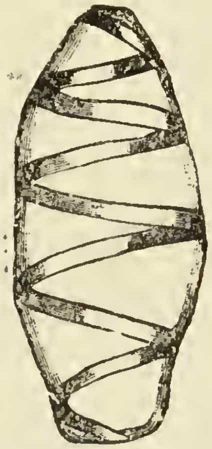

Fig. 34.—A spiral cell from a cactus, with strongly thickened spiral band.

when the thickening is deposited as a spiral, we get **spiral cells** (Fig. 34).

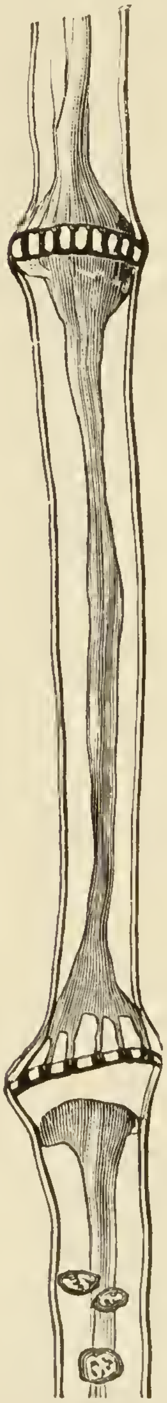

FIG. 35.—Sieve-tube from the white bryony, *Bryonia dioica*, the horizontal partition - walls with peculiar thickenings. (× 250.)

In some parts of a plant the cells undergo a great increase in length with more or less thickening of the walls, and such greatly elongated cells with pointed ends are said to be fusiform or spindle-shaped, and to form **fibres** (Fig. 2, B). Fibrous cells, therefore, are very long thick-walled cells with tapering ends. It must be understood that growth in the thickness of a cell wall is often accompanied by a change in the substance forming the wall, the wall becoming in some cases hard and rigid, and in other cases flexible.

22. Vessels.—By the absorption of the transverse wall of several elongated cells that lie in the same line, tubes are formed. Such tubes are termed **vessels**, and they are often of considerable length. The long tapering cells called fibres, together with some vessels, form the principal part of the wood of stems and branches, as well as the main part of petioles and the so-called veins of leaves. The living contents of the vessels become absorbed, so that when fully formed they contain only air or water. The vessels, like the cells, are usually named according to the markings on their inner walls, so that there are **pitted vessels, annular vessels, spiral vessels**, etc. (see Fig. 39).

When several cells in the same line have their separating walls merely perforated like a sieve, vessels called **sieve-tubes** are formed. Such vessels contain nutritive material. **Lactiferous** vessels are branching tubes that often form a network permeating the tissues of a plant. They convey a kind of milky sap.

23. The Tissues of a Plant.—The different kinds of cells, fibres, and vessels that form the substance or material of any of the higher plants are associated in groups of various forms, and such associated groups of cells and cell derivatives are called **tissues** (par. 4).

The various kinds of vegetable tissue may be classified according to their **shape** or **function.** When classified according to **shape,** we find two chief types of plant tissue, **parenchyma** and **prosenchyma.**

Parenchyma tissue consists of rounded or angular cells, the diameter of which is nearly the same in all directions (Fig. 29). Parenchyma is abundant in the growing and succulent parts of plants. It is mainly of use in taking up and storing food material. **Prosenchyma tissue** consists of groups of long narrow fibrous cells or vessels. It is mainly of use in conducting fluids and in mechanical strengthening. Thick-walled tissue of either of the above two kinds is termed **sclerenchyma** (Gk. *skleros*, "hard").

Classified according to **function,** tissues are divided into "meristem tissue" and "permanent tissue."

Meristem tissue consists of thin-walled living parenchymatous cells that are still capable of dividing to form new cells. Meristem tissue is, therefore, also called **formative** tissue. It is found at the growing points of roots, at the tip of shoots and buds, and in a certain region of the stem, where it is called **cambium.**

Permanent tissue includes all the fully developed tissues that have lost the power of further division. According to their **position** and form, the permanent tissues are subdivided into (*a*) the Epidermal Tissue, (*b*) the Fundamental or Ground Tissue, (*c*) the Fibro-vascular Tissue. As the name implies, the epidermal tissue is the tissue covering the young plant like a skin. In older plants, however, it is replaced in all parts except on the surfaces of the leaves. The ground or fundamental tissue is the mass of tissue filling all the space inside the epidermis, except that occupied by the strands called fibro-vascular tissue. Each of these three kinds of permanent tissue, however, need fuller description.

24. Epidermal Tissue.—The epidermal tissue or epidermis of a plant is the surface tissue which covers nearly all the green parts that are exposed to the air. This epidermis may be torn off many fleshy leaves as a thin transparent film. Examined under the microscope, the epidermis is seen to consist of a layer of flattened closely fitting cells, which are of different shape in different kinds of plants. The outer wall of an epidermis cell is often somewhat thickened to form a **cuticle**, and the cell-contents consist of a clear liquid. Scattered at intervals over the epidermis are pairs of small kidney-shaped cells with their ends in contact, but with an oval space between the pair in the middle. Each pair of cells forms an opening which is called a **stoma** (pl. stomata), and the cells forming the opening are known as the "guard cells" of the stoma (Figs. 36 and 84). They differ from the other cells of the epidermis, not only in shape, but also in containing chlorophyll. The stomata open into air-spaces between the cells of the body of the leaf, and serve for the interchanges of gases between the plant and the air (par. 52, Fig. 84). They also allow the escape of water-vapour from the cells of the interior. The stomata open or close according to the state of the atmosphere, remaining open under ordinary conditions, but closing in very dry or damp weather. They are most numerous, as a rule, on the under surface of leaves, several thousands often occurring on a single leaf.

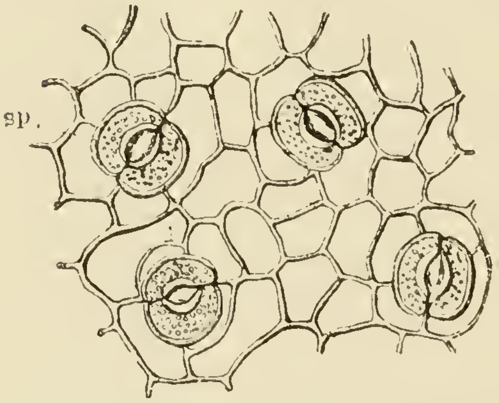

Fig. 36.—Horizontal section through lower epidermis of a leaf, showing four stomata with the guard cells.

The **hairs** of plants are produced from cells of the epidermis, and consist of one or more long cells. They are found on all parts of a plant, and serve various purposes. Root-hairs are unicellular outgrowths of the root epidermis, and serve to absorb water with any substance in solution (par. 45).

25. The Fundamental Tissue.—Within the epidermis that covers the stem of a young plant as a membrane or skin there lies a mass of variously shaped parenchyma cells (the fundamental or ground tissue), through which run longitudinally strands or stringy cords formed of bundles of fibres and vessels. A leaf, for example, consists of such ground tissue lying between the upper and lower epidermis, and traversed by strings of fibro-vascular tissue that form the midrib and the numerous so-called nerves or veins. In the young herbaceous stem of a bean plant or any other dicotyledonous plant, the arrangement of the three kinds of tissue is striking and important.

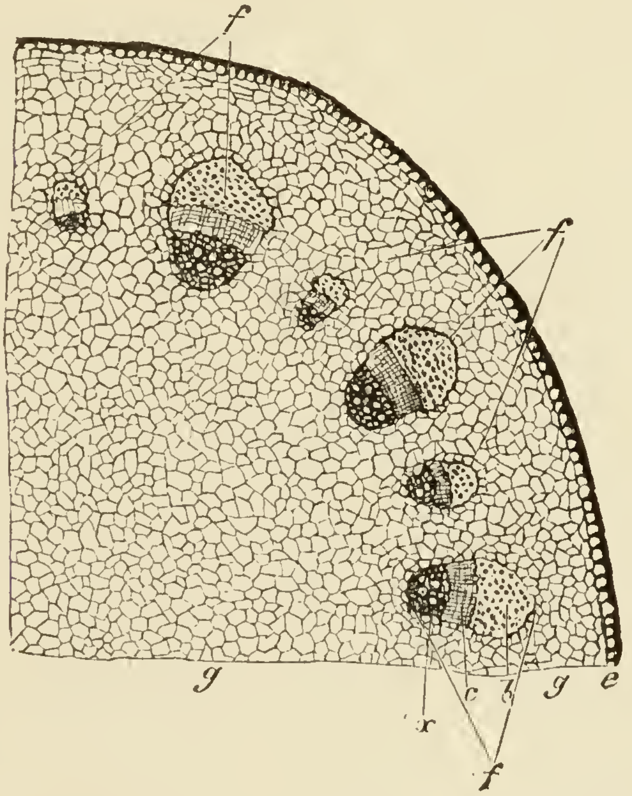

FIG. 37.—Transverse section of petiole of Hellebore, showing the three systems of tissues. *e*, epidermal; *f*, fibro-vascular; *x*, xylem; *c*, *b*, phloëm—*c*, soft bast; *b*, bast-fibres; *g*, ground or fundamental tissue. (After Prantl.)

On the outer surface we find the thin tissue of cells called the epidermis. Within the epidermis, as is shown by a transverse section, we find a number of oval stringy strands arranged in a circle at a distance from the centre and embedded in a mass of parencyhma cells. This mass of parenchyma cells, *i.e.* all the tissue of the stem, except the epidermis and fibro-vascular bundles, forms the ground or fundamental tissue. It is divided into three parts, the **pith** or **medulla**, occupying the centre ; the cortex, lying between the epidermis and the outside of the oval bundles ; and the **medullary rays**, forming bands between the vascular bundles and connecting the pith and the cortex.

The ground tissue of the leaf is largely nutritive in function, as will be explained later (par. 52). The cortex of a stem contains many living cells, some of which serve to store reserve material, and some of which contain cells with thickened corners that serve to give firmness to the stem. The medullary rays and the pith consist of thin-walled cells, but those of the pith usually lose their living protoplasm early.

26. The Fibro-vascular Tissue.—The fibro-vascular tissue (sometimes called vascular tissue simply) consists of strands or cords made up for the most part of fibres and vessels. They begin in the tips of the roots, pass up the stem, in which some pass out at the internodes into the stalks of the leaves, and finally end in fine strings that form the leaf-veins. As these vascular bundles form the conducting tissue of a plant and the channels of communication between different parts

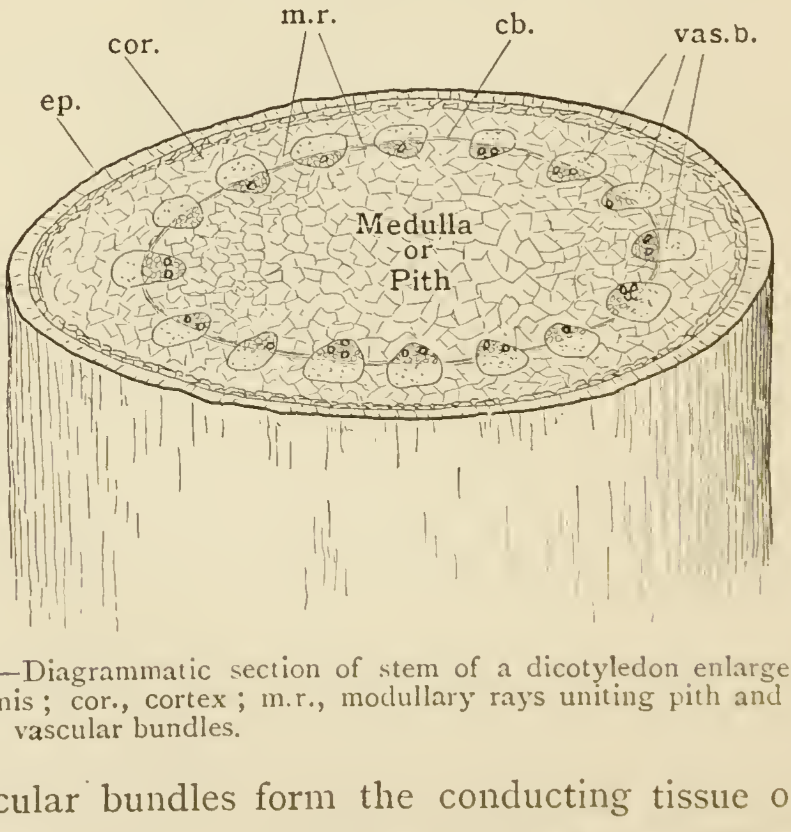

FIG. 38.—Diagrammatic section of stem of a dicotyledon enlarged. ep., epidermis ; cor., cortex ; m.r., modullary rays uniting pith and cortex ; vas. b., vascular bundles.

above, their construction may be somewhat more fully explained.

In a typical fibro-vascular bundle of a young dicotyledonous stem we find in reality three kinds of tissue—

1. **Xylem**, or wood next to the central pith.
2. **Phloëm**, or bast next to the cortex.
3. **Cambium**, a thin-walled meristem tissue between the xylem and phloëm.

The **xylem** is made up of **spiral** and **pitted vessels**, between which lie long cells with thickened lignified walls and tapering ends known as **wood fibres**, as well as a few parenchyma cells. Both the vessels and fibres soon use up their protoplasmic contents to thicken their walls, and then become conducting channels merely.

The **phloëm** or **bast** consists of sieve-tubes or bast vessels arranged end to end (Fig. 39), small companion cells with living contents, and bast fibres with cellulose walls. The bast vessels serve for the conduction of various organic substances.

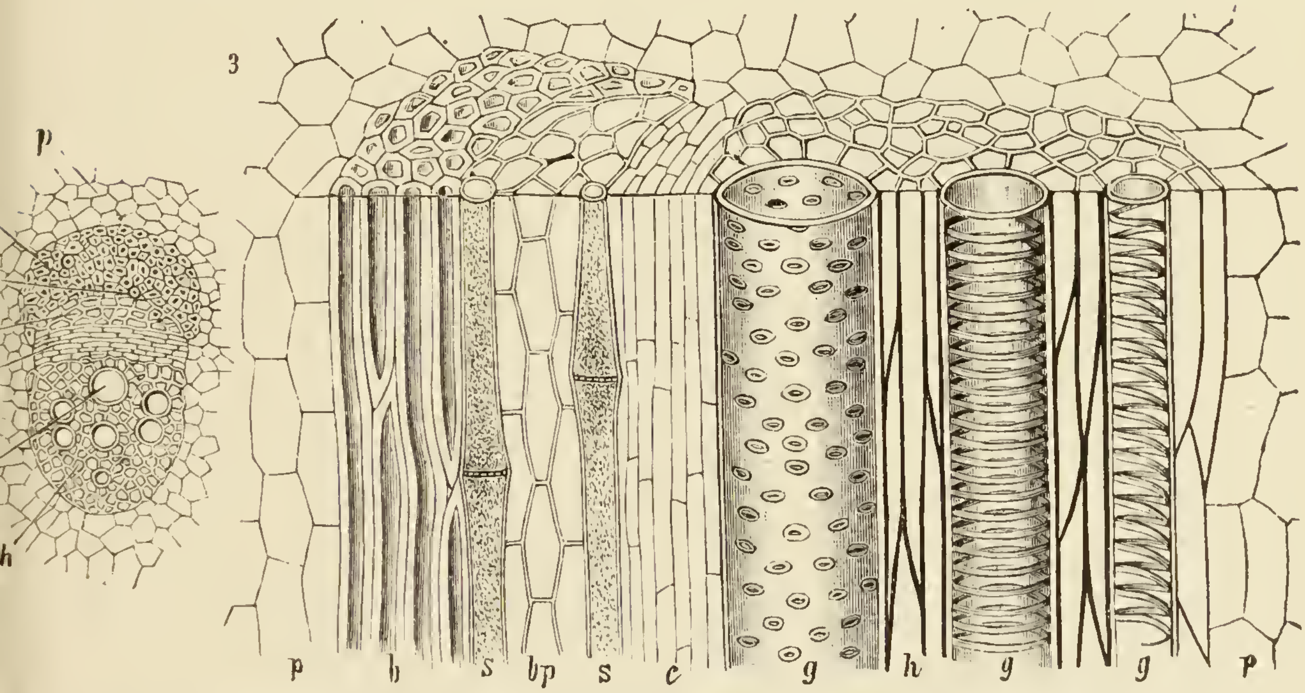

FIG. 39.—Cross-section of one of the fibro-vascular bundles in the stem of a sunflower (see Fig. 38). *h*, *h*, wood cells; *g*, *g*, vessels of the xylem part of the bundle; *c*, cambium cells; *bp*, parenchyma of the bast; *s*, sieve-tubes; *b*, bast cells; *p*, cells of the surrounding ground tissue. In the right-hand figure, the same fibro-vascular bundle is shown both in cross and longitudinal section, more highly magnified with lettering as in smaller cross-section. Somewhat diagrammatic. (Wettstein.)

The phloëm system, together with the cortex outside, forms what is known in older stems as the **bark.**

The **cambium** is a thin layer of delicate living cells between the xylem and bast. They retain the power of division, adding to the bast on their outside and to the xylem or wood on the inside. In young stems the cambium is confined within the vascular bundle, but as the stem becomes older the cambium layer of one bundle passes across the medullary rays to join that of another, and a complete cambium ring is thus formed (Fig. 38).

With the aid of Fig. 39, the reader will be better able to understand the character of the cells and vessels that enter into a vascular bundle of a young stem.

27. Function of the Vascular Bundles.—As already stated, one function of the vascular bundles of a plant is conduction—conduction of water by the wood fibres and vessels, and conduction of organic compounds (proteids) by the bast. Another function is that they serve the mechanical purpose of strengthening, and thus aid in keeping a plant firm and upright.

The vascular system of the root is connected with that of the stem, but the arrangement of the xylem and phloëm elements is somewhat different. A root consists of a central vascular cylinder surrounded by a cortex, with a root epidermis or piliferous layer outside. From this outside layer of cells root-hairs are developed in certain parts. The axis cylinder has inside vascular bundles running up in alternate cords of phloëm and xylem, with some parenchyma cells forming a pith in the centre.

It is thus clear that the cords or strands that form the vascular bundles form a connected system passing from the root-system into the stem, branches, leaves, and buds. (A diagrammatic arrangement of these bundles is represented in Fig. 82.) If the whole of the softer tissues of a plant were removed, the network of vascular bundles would still form a kind of skeleton model of the plant.

28. Structure of Woody Stems.—In any young herbaceous stem of a dicotyledon we have seen (Fig. 38) that there is a considerable mass of central pith, a ring of scattered fibro-vascular bundles, a cortex united to the pith by broad medullary plates, and an epidermis. In the trunk of a tree like the oak several years old we find that there is only a small pith in the centre, and that the bulk of the stem is made of wood in concentric rings. There is an outer covering called bark, but the epidermis has gone. How has the change from the herbaceous to the woody stem been effected? Early in the growth of the stem the cambium layer between the xylem and phloëm of the vascular bundles bridges across the intervals between the vascular bundles and forms a continuous cylinder of multiplying cells (Fig. 38), with the woody tissue inside and the phloëm and cortex outside. In the second year new vascular bundles form between the first bundles, and the cambium then forms on the inner side new wood cells and vessels, and on the outer side new phloëm, and as the vascular bundles unite, there comes to be formed a cylindrical shell of wood each year. The wood thus formed causes the pith to shrink, and, the bundles coming together, the medullary rays become squeezed into narrow radial plates. Each year the cambium cylinder forms in spring and summer a ring of wood and a thinner ring of phloëm, the wood thus increasing in thickness by additional rings to its outside. The appearance of the wood in **annual rings** is due to the fact that the wood formed in spring has larger vessels and is more open than the denser wood of summer and

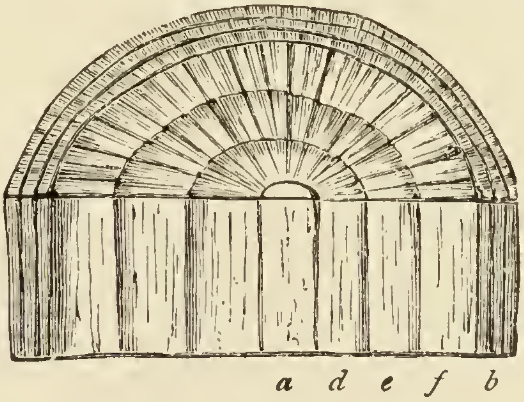

Fig. 40.—A three-year-old stem in cross and longitudinal section. *a*, pith; *b*, bark; *d*, woody cylinder of first year; *e*, of second year; and *f*, of third year.

autumn, and the rings thus mark where the close autumn wood ends and the more open wood of next spring begins. New medullary rays are also formed by the cambium each year, and those starting in the wood of the year are shorter and shorter than the primary medullary rays that reach the pith.

In most woody trunks the part of the stem outside the cambium ring is called the **bark.** At first it consists of the phloëm or bast; next to the cambium ring, a cortex of fundamental tissue, and the epidermis. The epidermis, however, is shed early. In the secondary bast the annual layers are much thinner and not so evident as in the wood, and the annual growth of wood squeezes out the bast and cortex, causing the older parts of the bark made up of these to crack and peel off, leaving only the new portion. The bark is, therefore, in most older trees, a comparatively cracked and thin cylindrical covering.

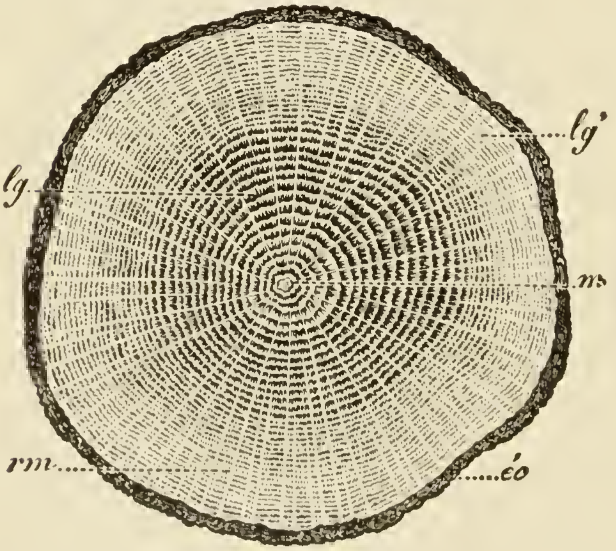

Fig. 41.—Section across the trunk of an oak, showing about thirty-five annual rings, the darker heart-wood and the lighter sap-wood, with medullary rays and bark. *m*, pith; *lg*, *lg'*, the annual rings; the light lines *rm*, medullary rays; *e'c*, the bark. (From Brown's "Manual of Botany.")

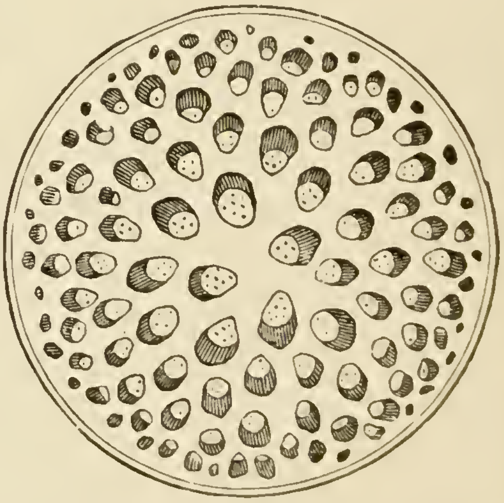

Fig. 42.—Diagrammatic representation of the distribution of the fibro-vascular bundles in the transverse section of a palm stem.

A structure of stem such as described above is seen in the trunk and branches of the oak, elm, and other trees.

They are said to be **exogenous**, because the wood increases by additions to its **outside**, the most exterior ring of wood being the newest. Besides the concentric annual rings of wood due to alternations of summer work and winter rest, many timber trees show in cross-section an inner more deeply coloured wood called the **heart-wood**, or **duramen**, and an outer paler wood called the **sap-wood**, or **alburnum.**

The inner layer of the bark in some trees, as the lime, is of a fibrous nature, so that this **liber**, as it is termed, is useful for cordage and matting.

In a monocotyledonous stem, such as a palm or sugar-cane, the structure is quite different from that just described. A cross-section shows that such a stem consists of a mass of ground tissue through which isolated vascular bundles pass, the bundles being scattered through the cellular tissue without much order, except that they are more crowded near the circumference. The cambium cells of each vascular bundle soon cease dividing, no cambium ring is formed, and no rings of wood. The closed vascular bundles are sheathed on the outside with thick-walled prosenchymatous cells, so that the outside of a monocotyledonous trunk is usually much harder than the centre. Little increase in the thickness of the stem takes place, so that such stems are nearly as thick at the top as the bottom. Such stems are called **endogenous** stems, from an old notion that the newest bundles were in the centre.

CHAPTER V.

THE LIFE-HISTORY OF THE BEAN.

29. The Broad Bean.—A common broad or Windsor bean, such as may be obtained from a seedsman at any part of the year, is one of the most convenient seeds for examination and cultivation. A dry and ripe bean seed is hard, and covered by a somewhat wrinkled buff skin called the **testa**, or seed-coat. On soaking the bean in water for twenty-four hours, it swells, loses the wrinkles in its coat, and becomes softer, owing to the water it absorbs. At one end of the seed is seen an elongated black scar called the **hilum**, and this scar marks the place where the broad end of the **funicle**, or seed-stalk, was attached when the bean was fixed in the pod. Close to one end of the hilum is a small hole in the testa, known as the **micropyle** (par. 17). This may be found in the dry bean with a lens, or it can readily be noticed by the water which oozes out on squeezing a soaked bean. By cutting through the testa along one edge of the bean the seed-coat is easily removed, and it is then seen that the greater part of the bean is made of two pale, thick, fleshy lobes, the inner faces of which are flat and lie against one another. These two fleshy lobes are called **cotyledons**, or seed-leaves, and are in reality the first leaves of the young bean-plant supplied with a store of food. The cotyledons are not completely separate from each other, for each one is attached near its base by a short stalk to a small conical body or axis lying between the cotyledons, as will be seen on removing one of these bodies. The portion of this axis which points towards the micropyle is known as the **radicle,** as it will develop into the root when the seed is sown. The radicle may even be detected just above the micropyle before the seed-coat is removed. The other end of the axis, which is bent and curved inwards, is known as the **plumule,** and ends in a bud situated at the end of the axis. It is the primary stem of the plant. The part of the axis just below the attachments of the cotyledons, and connecting the young root and the young stem, is termed the **hypocotyl** (Gr. *hypo*, "under"). The radicle or young root, and the plumule or young stem and bud, together with the two cotyledons, form the rudimentary plant, or **embryo**. Other seeds, as the pea and the almond, consist of a similar embryo. Plants arising from seeds having two cotyledons are called **dicotyledonous plants**. To sum up, we find that a ripe bean is a seed consisting of a membranous testa enclosing an embryo; that the embryo consists of two large cotyledons and an attached axis made up of a small radicle and a small plumule; and that the tip of the radicle points to the micropyle, found near one end of the hilum or scar of the testa.

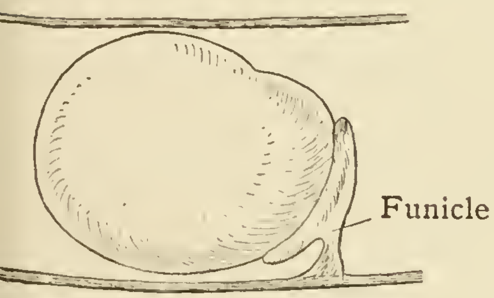

FIG. 43.—Broad bean in pod, showing mode of attachment by funicle.

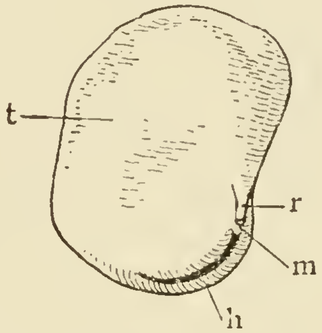

FIG. 44.—Broad bean from outside. t, testa or seed-coat; r, radicle; m, micropyle; h, hilum.

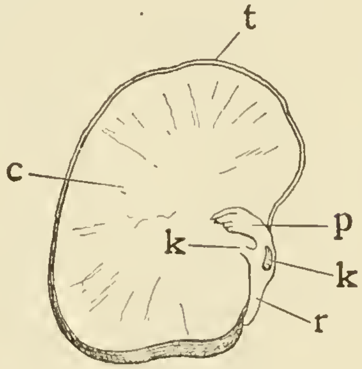

FIG. 45.—Bean, one cotyledon removed, showing inner surface. t, testa; c, cotyledon; r, radicle; k, k, stalks of cotyledons; p, plumule.

30. Germination of the Bean.—A dry, ripe bean will remain without change for many months, as the life of the embryo appears to be capable of assuming a dormant or resting state. Under suitable conditions, however, such a seed will begin to grow or germinate, as will be seen by the growth of the radicle and plumule. Germination may be called the awakening from a dormant state to active growth. The conditions of germination are three: moisture, a suitable temperature, and the access of air or oxygen. Unless all three conditions are fulfilled, germination will not take place. Dry seeds never germinate. A certain temperature above freezing-point is also requisite, but this varies with different seeds. With beans the most suitable temperature is about 28° C. (82·4° F.). Above or below this germination goes on slowly. Air or oxygen is also necessary. In ordinary case, the seed obtains this oxygen from the air entangled in the particles of soil. To show the necessity of oxygen for germination, a number of beans may be placed in a bottle supplied with a little water and kept at the suitable temperature. Fill the bottle with carbon dioxide or hydrogen, and then cork tightly with a rubber stopper. No germination will take place (see also par. 67). In the germination of the bean, the first thing that happens is the bursting of the seed-coat by the radicle at the micropyle, and the elongation of this part as it grows downwards to form the primary root. After the radicle has grown some time, the plumule forces its way out from between the cotyledons, and, pushing aside a flap of the seed-coat, raises itself upwards, but keeping its upper end in the form of a hook (Figs. 46 and 47). Hence, when a bean is placed in damp soil and allowed to germinate, the first part that emerges is the hook or the curved outline of the rudimentary stem, with the tip of the plumule downwards. In this way the delicate tip of the plumule is protected from injury as it passes upwards through the soil. This tip is really a bud, consisting of a short portion of the stem surrounded by leaves. When the bud straightens up, the leaves of the plumule begin to unfold, and the stem between the crowded leaves begins at once to lengthen. The cotyledons, although they are undoubted leaves, remain within the seed-coat beneath the ground. They do not increase in any way, but give up their store of food to the growing root and stem. While the plumule has been emerging above ground, the radicle has been increasing in length, and also giving off lateral branches. The main root, called the **tap-root**, not only gives off branches, but also gives rise, at some distance from its growing point, to fine hairs. These hairs also arise on the root-branches, leaving, however, a portion near each pointed end quite free of hairs. It should be noted that in whatever position the bean seed may be sown, the radicle will turn *downwards*. The property of the seed manifested in the radicle emerging first and growing downwards into the soil is evidently an advantage to the plant, which is thus fixing itself and getting ready to absorb water and dissolved mineral matter from the soil.

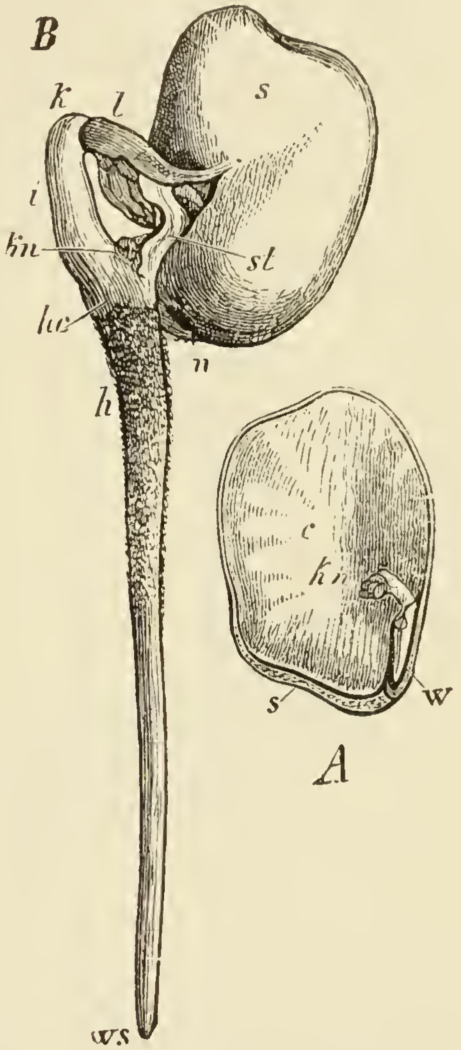

FIG. 46.—*A*. Seed of bean. One cotyledon removed, showing *c*, the other cotyledon; *s*, testa; *kn*, plumule; *w*, radicle.

B. Germinating embryo of bean. *hc*, hypocotyledonary stem; *i*, *k*, stem; *l*, flap of seed-coat; *st*, stalk of cotyledon; *kn*, bud; *h*, root-hairs.

31. Further Growth of the Bean Plant.—As just stated, after the plumule has come out of the ground and placed itself upright, the short part of the stem inside the bud elongates, and the leaves, which are at first crowded together upon it, become separate from each other. The extreme tip, however, called the **growing point**, because it is there that new cells are constantly being formed to produce more stem and leaves, continues to be protected by enfolding young leaves. After the stem reaches a certain length between the lowest leaves, this part ceases to lengthen. Successive internodes of a certain length are produced above, until the plant, in the course of the season, reaches a height of three feet or more, though the internodes are shorter and shorter towards the summit of the stem (Fig. 50).

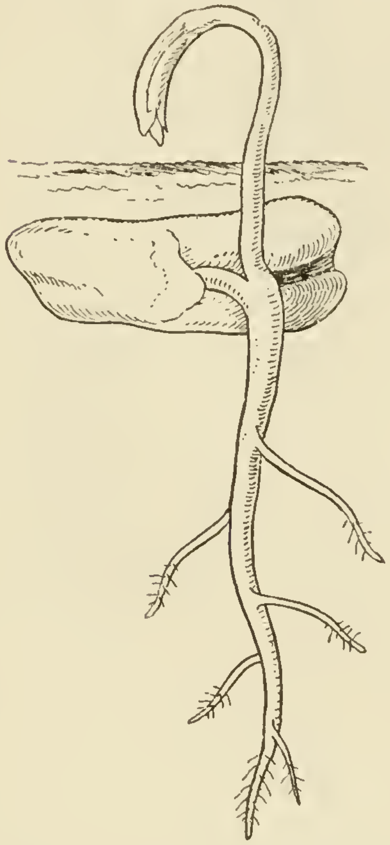

FIG. 47.—The bean with the plumule above the ground and rootlets from the main root; root-hairs indicated.

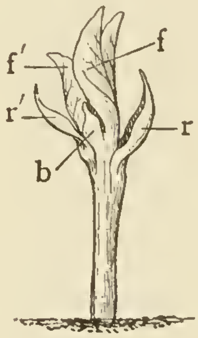

FIG. 48.—Plumule of the bean unfolding. r and r′, the first rudimentary leaves; f and f′, the first foliage leaves; b, bud.

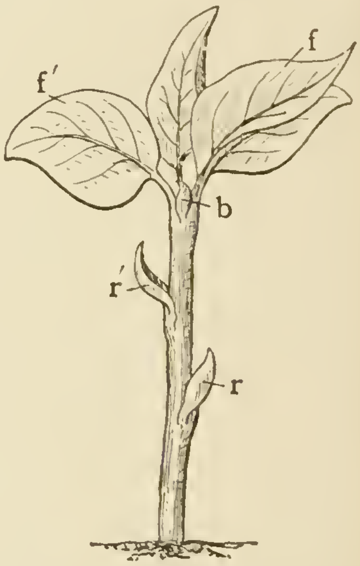

FIG. 49.—Later stage of growth of bean-stem; references as in Fig. 48.

The first two leaves, it will be noticed, are of a simple and rudimentary kind. The ordinary foliage leaves of the bean are developed from nodes at opposite sides of the stem, and consist of a stalk or petiole with from two to six green oval leaflets. In the axils of the leaves buds are also developed. Some of these may give rise to a branch which bears leaves, but others grow into stalks which bear a flower having the usual four whorls—calyx, corolla, stamens, and a pistil. Let us consider the parts of a full-grown plant in detail.

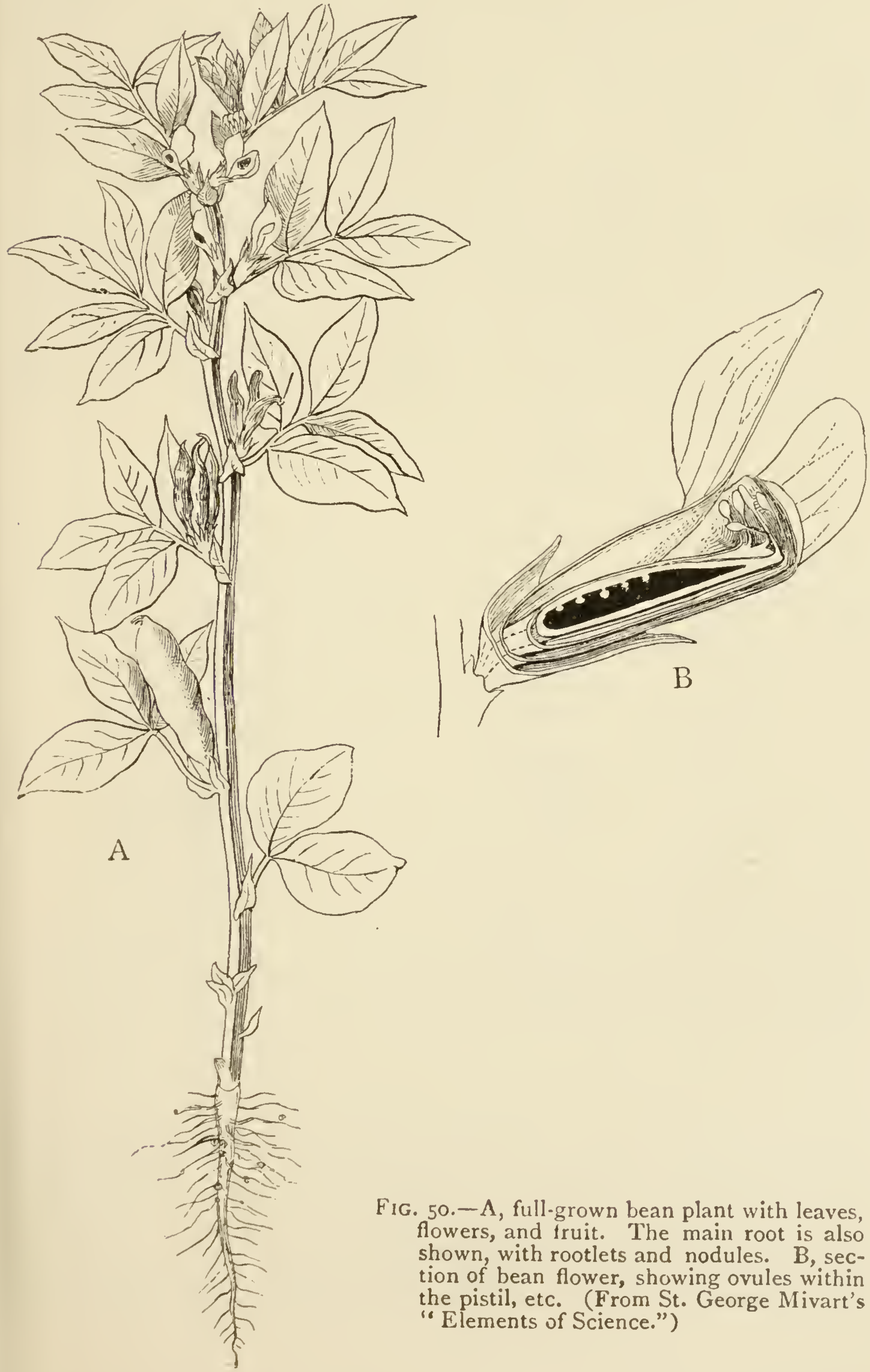

Fig. 50.—A, full-grown bean plant with leaves, flowers, and fruit. The main root is also shown, with rootlets and nodules. B, section of bean flower, showing ovules within the pistil, etc. (From St. George Mivart's "Elements of Science.")

Experiments.—Soak some broad beans for a day, and then examine one. Weigh before and after soaking. Remove the testa and observe the positions of the various parts of the embryo. Take away one cotyledon, noting the stalk of the cotyledons united to the axis of the plantlet, and the form and position of the plumule. Make drawings. Fold up some of the soaked beans in damp flannel, placing one lot in a warm room and another lot in a cold cellar. Observe that the radicles first appear through the testa in those that are in the warm room. Continue the germination, keeping the flannel moist. Note that the radicle grows considerably before the plumule escapes from the testa. Put other soaked beans in soil or damp saw-dust, and examine one every day or two. Notice how the cotyledons shrink as the seedling grows and uses up their store of food. Notice, also, how the radicle grows downward and the

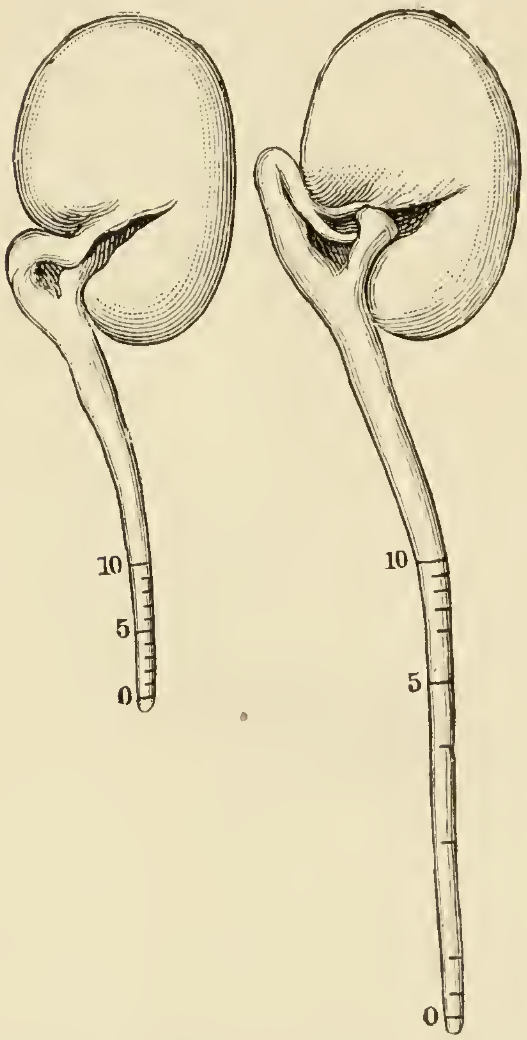

FIG. 52.—Germinating bean. On the left the lower part of the young root has been marked in millimetre divisions. On the right is shown the same bean after 24 hours' further growth, the separate divisions having grown unequally, and the greatest growth having occurred between divisions 2 and 5.

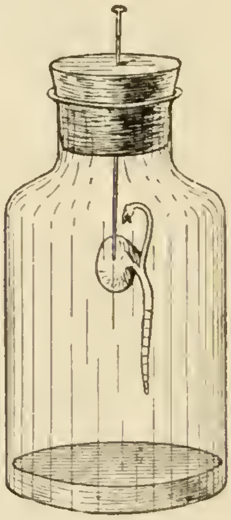

FIG. 51.—Bean germinating in bottle over water, and root marked to find region of greatest growth.

plumule upwards whatever be the position of the seed in the soil. Take a seed the radicle of which is just over an inch in length, mark with Indian ink on the radicle millimetre divisions, and then suspend it in a bottle containing a little water (Fig. 51). Observe that the region of greatest growth in the radicle is at a short distance from the tip. Note, also, the position of the root hairs on the radicle and the formation of lateral roots. Mark the *stem* with Indian ink and find the region of greatest elongation—the part a little below the growing point (par. 33).

32. The Root of the Bean Plant.—The root consists of a main central part termed the **tap-root**, from which are given off at irregular intervals branches termed secondary roots or **rootlets** (Fig. 47). These may, in some cases, give off branches also. At a short distance from the end of each root minute root-hairs may be observed with a lens. Rootlets have their origin from a central strand of fibres and minute vessels, but root-hairs spring from the **outer** covering of cells. As we shall shortly learn, these root-hairs are the chief absorptive agents of the plant, taking up from the soil

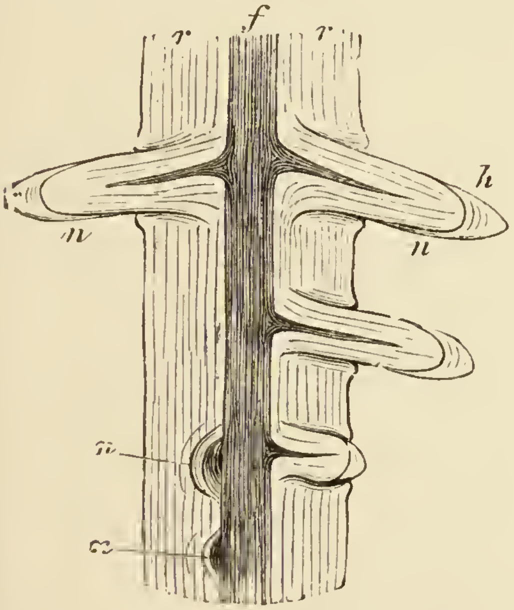

FIG. 53.—Longitudinal section of main root of bean. *r*, *r*, cortex of main root; *f*, fibro-vascular bundles; *n*, *n*, lateral rootlets developing from central interior, and breaking through cortical tissue; *h*, root-cap of side rootlets. (After Prantl.)

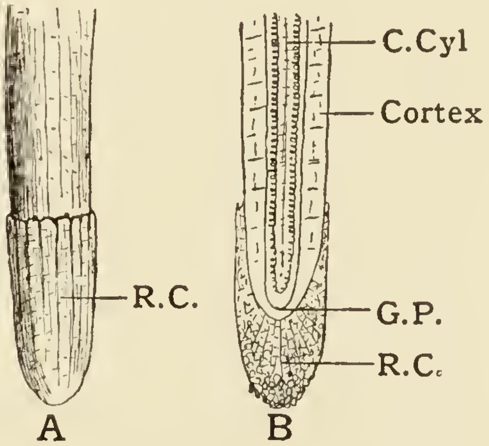

FIG. 54.—Rootlet magnified to show root-cap. A, from outside; B, in section; R.C., root-cap; G.P., growing point of true rootlet; C.Cyl., central vascular cylinder.

water and dissolved mineral food. They are only found near the root-tip, dying off from the older parts. If a young rootlet of a bean is washed, held up to the light, and examined by a good lens, it will be seen to end in a conical point of soft material, within which the curved outline of the end of the true root may be observed. The real tip of each rootlet is, in fact, covered with a **root-cap**, somewhat in the same way as a thimble with a thick rounded end covers the tip of the finger. The root-cap really consists of a protective covering of cells that are constantly being worn off as it goes deeper into the soil, and as constantly being renewed at the apex of the true root, which is termed the **growing point.** The growing point is the region where new material is constantly being produced, not only for the root-cap, but also for the main body of the root (Fig. 54).

It is easier to see and examine the root-cap of a water plant like duckweed than that of the bean, as it is difficult to get an uninjured root-cap out of the ground. On the roots of the bean (Fig. 50) will be seen a number of small *nodules*, or tubercles. Similar nodules are found on the roots of the pea, laburnum, vetch, and other members of the bean family. These nodules or root-tubercles are produced by microscopic bacteria, and are found to enable leguminous plants to absorb in some way the free nitrogen of the air, though it is a general truth that plants obtain the nitrogen they require from nitrogenous compounds termed nitrates present in the soil, and not from the nitrogen of the air (par. 46). The exception just stated is, however, important. Probably the bacteria live on the food-materials in the cells of the tubercles, and at the same time absorb atmospheric nitrogen, and this enters into combination and forms some of the nitrogenous compounds of the plant.

33. The Stem of the Bean Plant.—The bean plant has an erect green stem which is somewhat four-cornered or square, with a ridge at each angle. The internodes shorten as we approach the apex. (The stem of the garden pea is a soft trailing stem that climbs upwards by means of leaf-tendrils.)

Owing to the soft nature of most of the tissues or materials forming the stem, it is called a **herbaceous** stem, as distinguished from a hard or **woody** stem. If we cut across a stem, we notice that it consists largely of soft tissue, in which are embedded a number of small stringy strands harder to cut than the rest. The stringy strands are the **fibro-vascular bundles** (par. 26), and they are arranged, as may be seen with a good lens (or better by examining a thin section under a low power of the microscope), in a circle around a central soft **pith**, or medulla (Fig. 38). These fibro-vascular bundles not only serve to give strength to the stem, but act as conductors of the watery fluid termed sap (par. 50). They are divided into two parts, xylem and phloëm, by means of a cambium layer (Fig. 39). Outside the ring of fibro-vascular bundles is the soft tissue termed the **cortex** of the stem, while the soft tissue radiating from the pith between the vascular bundles to the cortex is spoken of as the **medullary rays.** The outer covering of the stem, or **epidermis**, is usually a single layer of flattened cells (see Fig. 36) with stomata at intervals. These stomata of the stem epidermis have the same function as those of the leaf (par. 52).

If a young growing stem be marked in centimetre or millimetre divisions, as was done with the young root, it will be found that elongation occurs in all the terminal portion of the stem, though the zone of maximum growth will be found in the two highest internodes of the stem.

34. The Leaves of the Bean Plant.—The leaves of the bean plant arise from the stem at alternate nodes, the internodes becoming less and less as we approach the summit. Each leaf, except the early rudimentary ones, is compound and consists of a stalk, or **petiole**, to which are attached from two to six ovate leaflets. The leaf margin is without indentations and the surface is smooth. At the base of the petiole there are two small leaf-like parts termed **stipules.** A branch of the leaf-stalk termed the **midrib** runs up the centre of each leaflet, and gives off on either side branches and sub-branches termed **veins.** Between the numerous veins lies a thin mass of soft tissue making up the substance of the leaf, and enclosed within a thin covering above and below termed *the upper and lower epidermis.* The further minute structure, as well as the function of the leaf, is described in Chap. VIII.

35. The Flower of the Bean Plant.—The flower of the bean is borne on a short stalk termed the **peduncle,** and the flower, when in full bloom, has its stalk and axis nearly horizontal. It is very similar to the flower of the garden pea, the sweet pea, the laburnum, and other allied plants, and all these flowers, owing to a fancied resemblance to a butterfly, are termed **papilionaceous** (Lat. *papilio,* "a butterfly"). A section of the bean flower is shown in Fig. 50, B, and will be understood after the description of the very similar flower of the pea which follows.

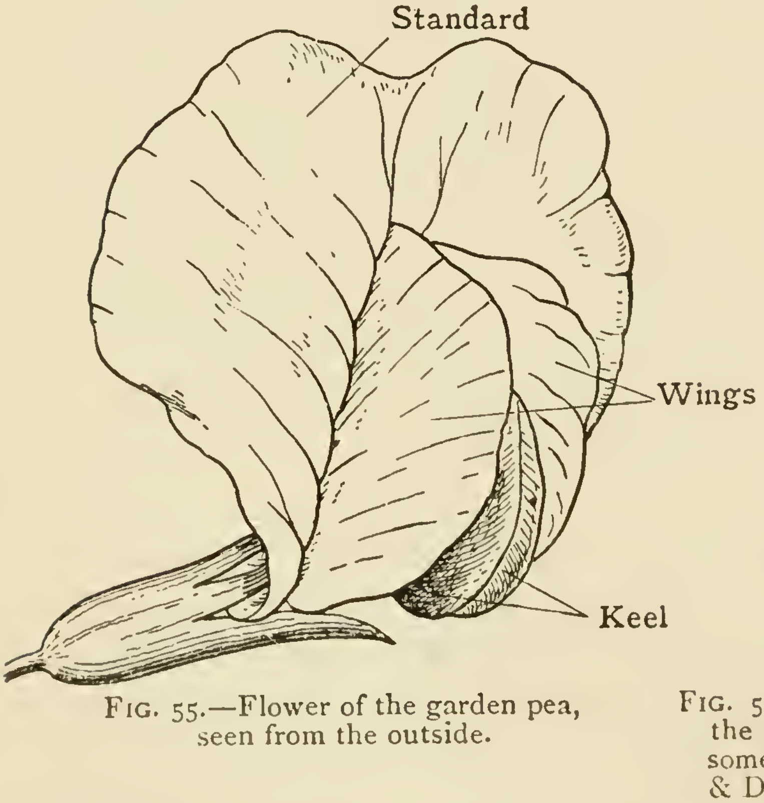

Fig. 55.—Flower of the garden pea, seen from the outside.

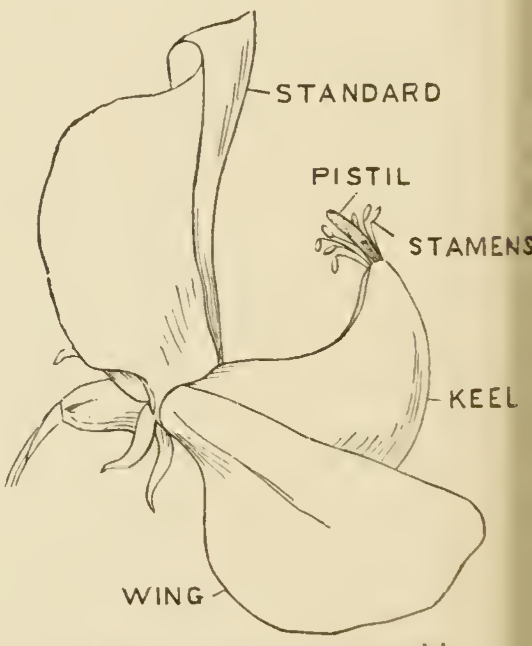

Fig. 56.—Flower of the sweet pea with the wings pulled down and the keel somewhat depressed. (From Garlick & Dexter's "Object Lessons.")

At the head of the flower-stalk is the small green cup known as the **calyx.** The edge of the tubular calyx bears five points, which indicate that five sepals cohere below to form this part of the flower. The **corolla** is also composed of five pieces or petals, but these do not show the same regularity of form and size as do the petals of the wall-flower or buttercup. Owing to the different shape of the petals in these flowers, special names are given to them. On removing the greater part of the calyx, the white corolla will be better exposed for examination. The large uppermost petal is the **standard,** or **vexillum.** Its narrow horizontal base lies over the bases of the other petals, while its broad free ends turn upwards (Fig. 55). Remove the standard and note the two similar oval petals on each side, which are known as the **alæ,** or **wings.** (In the bean flower each wing has a black spot near the middle.) Take away the wing petals, and there remain below two other oval

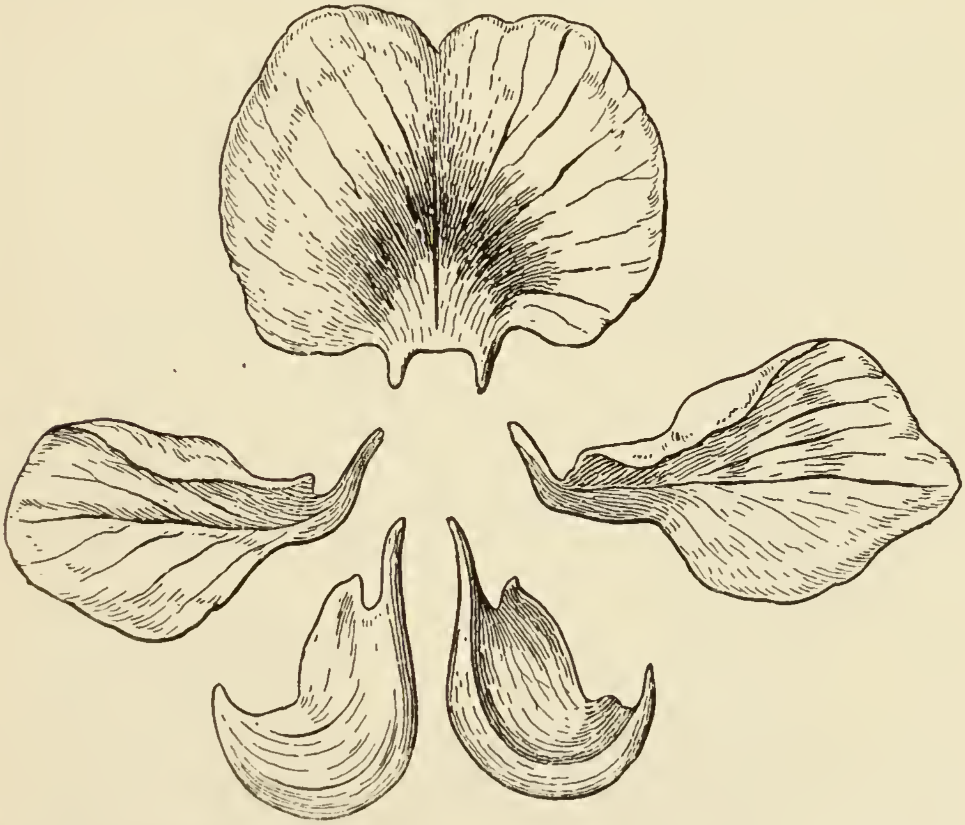

FIG. 57.—The separate petals of the flower of the garden pea, the two lower ones that form the keel being separated.

petals arranged in the form of a boat, owing to being lightly united along their lower edge. This lower part of the corolla is known as the **keel**, or **carina**. On pulling down the keel and detaching it, we find the ten **stamens** that are contained within the keel. The stamens each possess a slender stalk or **filament**, with a knob-like **anther** at the free end. Nine of these stamens show a remarkable arrangement, for their filaments are united together for about two-thirds of the distance from their point of origin on the calyx, so as to form a tube split above, but the tenth upper stamen is free, as may be seen by raising it with a needle. The free ends of the stamens all curve upwards, and the bi-lobed anthers open by longitudinal seams so as to allow the pollen to fall into the keel.

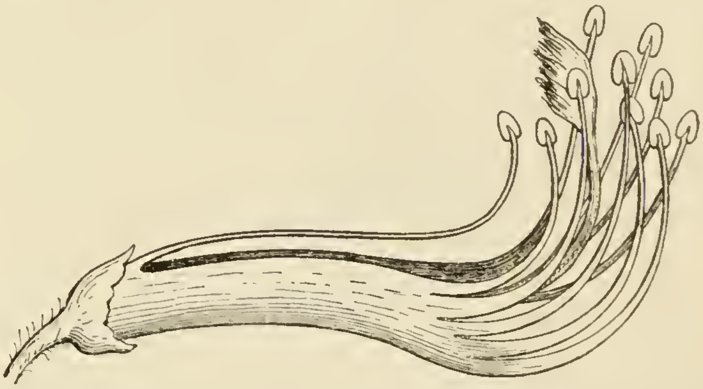

Fig. 58.—The central part of the pea flower after removing the petals and the greater part of the calyx, and showing the ten stamens, nine of which have their filaments united below to form a tube, while the tenth is free. The style and stigma of the enclosed pistil are also seen.

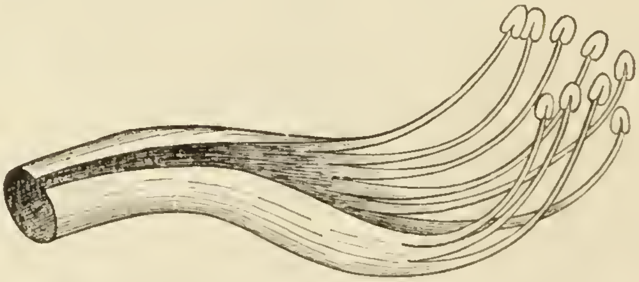

Fig. 59.—The staminal tube of the pea flower detached.

On carefully cutting away the stamen-tube we see the whole of the pistil, the central and most important organ of the flower. The long somewhat flattened **ovary** of the pistil is found within the stamen-tube, but the style protrudes and turns upwards, ending in the **stigma.** Note the brush of hairs, one at the end of the style facing the flower just below the stigma. A longitudinal section of an ovary or pistil will show that it consists of a single carpel united so as to form a cell, and that in this cell are contained the small oval bodies termed **ovules** (Fig. 50, B). These are attached by a short stalk to the upper border of the ovary.

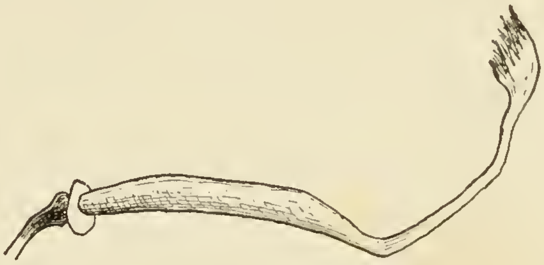

FIG. 60.—Pistil of pea flower, with style and hair brush near the stigma.

After fertilization of the ovary by the pollen in the way described in pars. 17 and 60, the flower fades and the petals

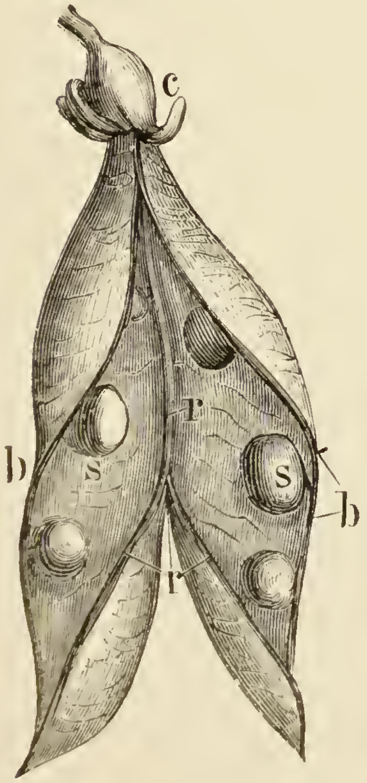

FIG. 61.—Pod of pea splitting along the sutures. r, outer or dorsal suture; b, inner or ventral suture; s, seeds.

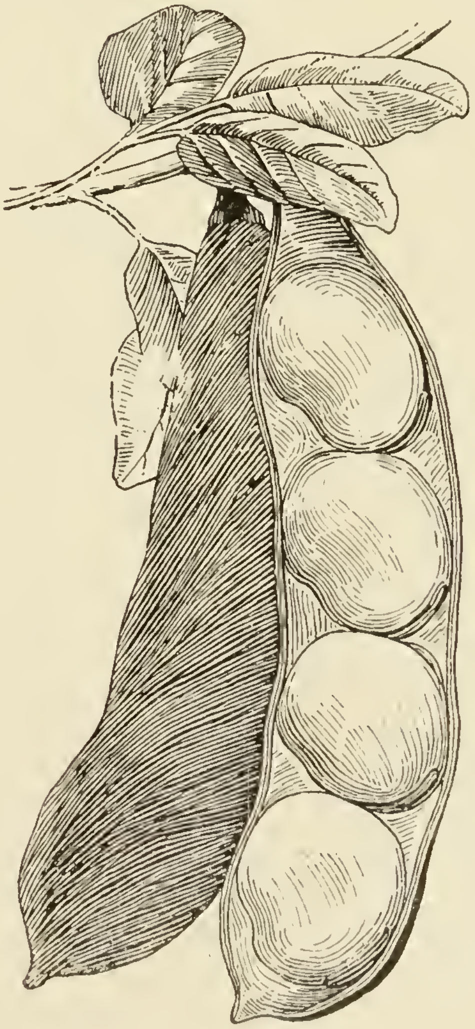

FIG. 62.—Broad beans in pod.

fall off, but the calyx remains. The ovary enlarges and becomes a pod, and the ovules turn to seeds, and the pod on reaching its full size becomes ripe, and, bursting along its edges, sets the seeds free. The enlarged and ripe ovary of the pea or bean is the fruit, and the seeds are the beans or peas, as the case may be. Botanists call such a fruit a **legume**, and plants having a legume pod are known as **leguminous plants.** (A legume is a fruit formed from a pistil of one carpel, which splits when ripe along both sutures, and lets the seeds attached to the inner suture fall out.)

Experiments.—Obtain plants of the bean and pea before flowering, in flower, and in fruit. Note how the flowers and fruit open and ripen from below upwards. Compare the position of the flower in each case in bud and when full blown. Observe the insects that visit the flowers. Compare also the flowers of each plant. Press down the wings of a flower that has just opened out, and note how the pollen is sent out from the keel in which it gathers (par. 63). Note also the difference between the inner lining of the pod of the garden bean and the pea. Compare the white flower of the garden pea with the coloured flower of the sweet pea. A Laburnum flower may also be examined. The flower of the Gorse or Furze may often be obtained when the other flowers are not available. Though essentially like the others, the following differences should be noted. The outer covering or calyx seems to consist of two brownish-yellow downy leaves, but they may easily be separated into five. The five yellow petals correspond closely to those of the bean or pea, but the ten stamens are all united into a stamen-tube. Another papilionaceous flower that may be examined is the common yellow Broom. It is very similar to that of the Gorse, but its style is much curved.

CHAPTER VI.

THE BRACKEN FERN.

36. Ferns in General.—The living objects forming the vegetable kingdom include everything that is called a plant, from the tiniest lichen or moss to the forest trees. This great kingdom is divided into two great groups called Flowering Plants, or Phanerogams, and Non-flowering Plants, or Cryptogams. The flowering plants include all the trees, shrubs, or herbs that bear flowers provided with stamens and pistils, either on the same or on a separate plant, and that are produced from seeds containing a distinct embryo. The flowerless plants are lower vegetable organisms that do not bear flowers giving rise to seeds possessing an embryo, but produce reproductive bodies consisting of a single cell termed a **spore**. Among the spore-propagated plants ferns form an important class. After we have considered one or two in some detail, we shall see that ferns may be generally described as *flowerless plants furnished with fibrous roots and creeping stems* (*rhizomes*) *that support leaves* (*fronds*), *on which are borne reproductive bodies called* **spores**.

In some ferns the stem runs horizontally underground, and is often mistaken for a root; in others it creeps along over the surface; while in others, known as tree-ferns, it is upright. The leaves or fronds springing from the stem are very various in form. The stalk of the frond, as it springs from the rhizome, is known as the **stipes**, till it reaches to where the leafy pad begins, when it goes by the name **rachis.** In most ferns the rachis branches from the first or primary rachis one or more times. The leafy portion of the frond is undivided in the common hart's tongue fern, but in most cases the leafy portion is divided, sometimes several times. When the margin is merely scalloped out without reaching the rachis, the frond is said to be **pinnatifid.** When the frond is divided quite down to the rachis, with a part quite bare, each distinct leaf-like division is called a **pinna.** A pinna itself is again in some cases completely divided, and then the frond is said to be **bipinnate.** Fronds may also be thrice pinnate, and in some ferns still more divisions are found. The ultimate flattened leaflets in all compound fronds are known as **pinnules.**

Another distinguishing mark of ferns is the mode in which the young fronds are rolled up. The rachis and its branches are rolled up from behind forwards, and only unroll as growth progresses.

The organs of fructification in ferns are spores contained in cases called **sporangia** (sing. *sporangium*), situated in most cases at the back or margin of a fully formed frond upon a thickening of a veinlet termed the receptacle. Each separate cluster or bundle of spore-cases is called a **sorus** (pl. *sori*). The sori are usually covered in the early stages by a membranous cover called the **indusium.**

37. The Bracken Fern.—A common bracken fern or Pteris consists of a rhizome or creeping stem that runs along underground, giving off green fronds that rise singly above the ground, and also many true fibrous roots that remain below. It varies in size and development according to the soil in which it grows, being small in a dry sandy soil, but larger in damp, rich, shady ground. An ordinary average specimen will have a rhizome as thick as a finger, and fronds three or four feet high. Fine examples may occasionally be found with fronds six or seven feet high. The subterranean stem of the bracken is almost black, and creeps along below the ground, often giving off branches. From its surface it gives off fronds year after year; the fully developed one of each year from each branch turning brown and dying down in autumn.

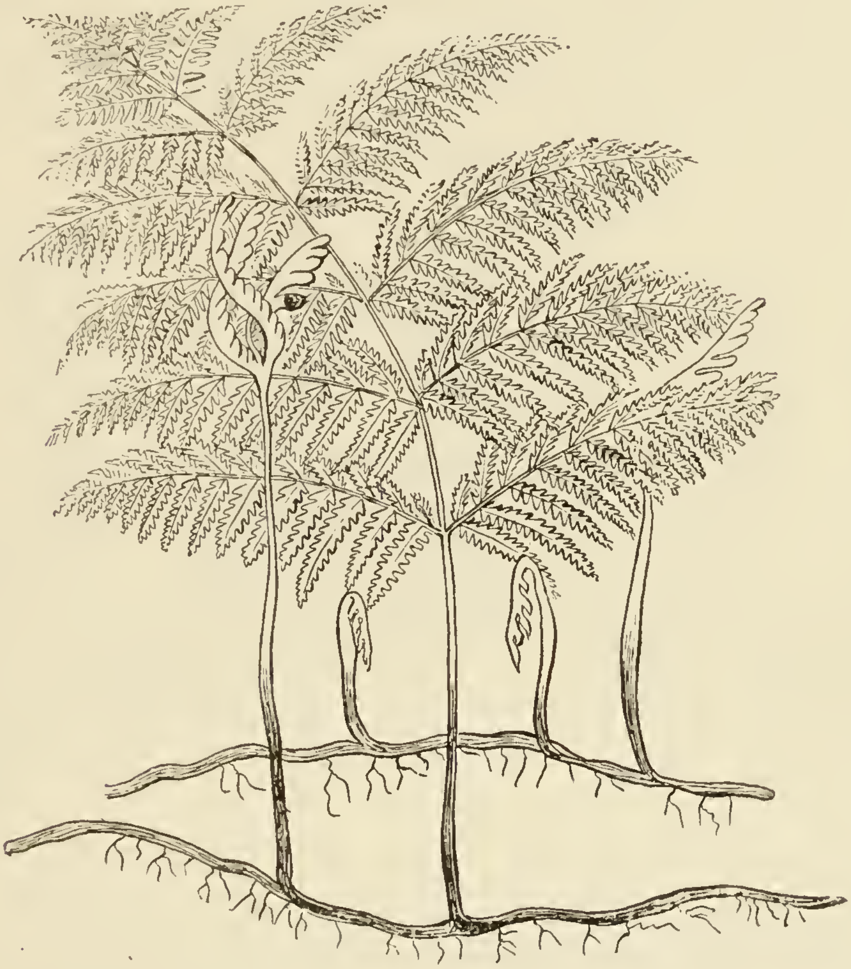

FIG. 63.—The bracken fern. Two rhizomes with roots, one showing a complete frond and a younger one, the other showing fronds unfolding. (From St. George Mivart's "Elements of Science.")

Let us now examine each part of the bracken in more detail.

38. The Rhizome of the Bracken.—On digging down and exposing the rhizome of a bracken, it is found to consist of a dark brown or blackish rough cylindrical body, with a lighter band (the lateral line) running along each side, and with filamentous roots. If we follow it from the point of attachment of the green frond, we find in one direction the dead and withered stalks of the fronds of previous years, while in the opposite direction are young fronds and rudiments of fronds that have not reached the surface. In this latter direction the rhizome ends in a conical apex, which is the growing point of the plant.

When the stem of the bracken is cut across transversely, it is easy to see with a lens, or even with the unaided eye, that it is made up of three or four kinds of tissues. Outside is a thin epidermis, and beneath this a layer of hard sclerenchyma, dark-brown or black in colour, and thinning away at the lateral lines, called the **hypodermis.** The inside of the section shows a main mass of soft whitish ground tissue or parenchyma, with patches and dots of two colours. The patches of dark colour are the cut ends of bands and plates of hard sclerenchyma that run through the rhizome lengthwise. The yellowish patches and dots are sections of vascular bundles, which consist mainly of phloëm and of spiral and scalariform (transversely barred) vessels containing water or air. The soft parenchyma is seen under the microscope to consist of polygonal cells filled with

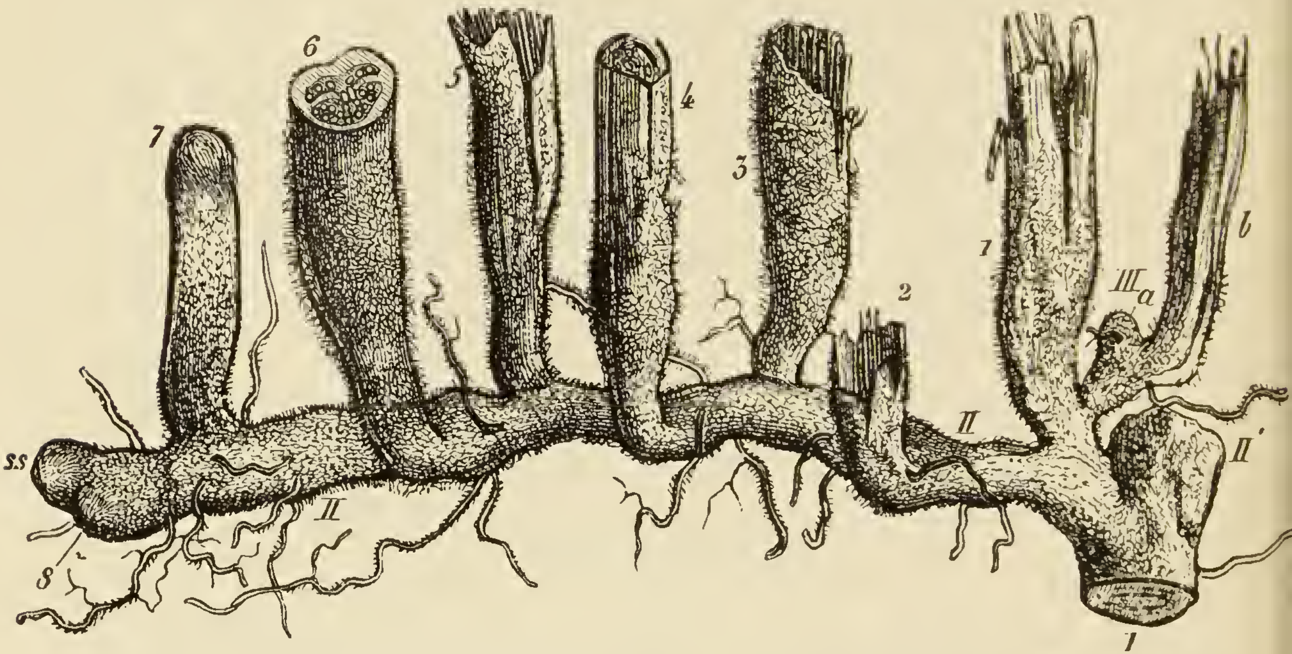

FIG. 64.—A portion of the underground stem of the bracken (*Pteris aquilina*), with leaves and bases of leaf-stalks, half the natural size. *I*, older portion of the stem, bearing two bifurcations, *II* and *II'*; *ss*, the apex (growing point) of the weaker branch *II*, close to it the youngest leaf-rudiment *s*; 1–7, the leaves of this branch, one of which is developed in each year; 1–5, the leaves of earlier years, which are already dead to a certain distance from the stem; 6, the leaf of the present year with unfolded lamina and with the stalk cut through; 7, the young leaf for the next year with its lamina still quite small and covered up with hairs at the apex of the stem. The leaf-stalk *I* bears a bud *IIIa*, which, after developing a leaf that is already dead, has now become dormant. The more slender filaments are roots. All the parts shown in the figure are subterranean. (Sachs.)

starch-grains that serve as a storehouse of food. On cutting a rhizome longitudinally, the longitudinal bands and rods of dark sclerenchyma and of yellow vascular bundles can be traced along until they gradually disappear in the soft gelatinous substance that forms the growing end of the underground stem.

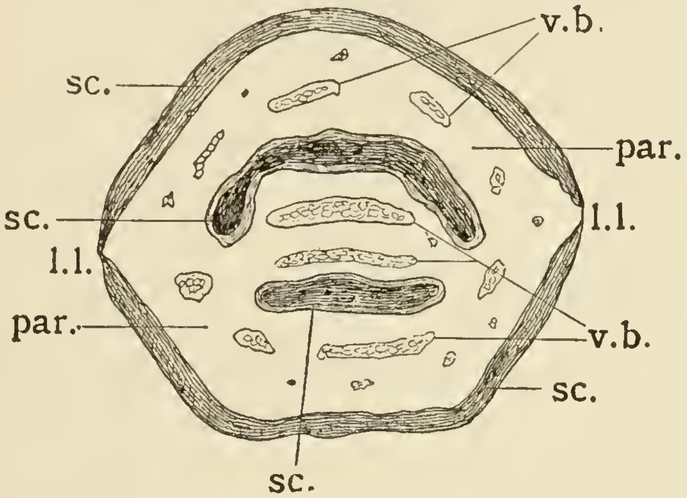

FIG. 65.—Transverse section of rhizome or underground stem of bracken. The lighter shading v.b. indicates the scattered fibro-vascular bundles, the darker shading the sclerenchyma, sc., the unshaded part the parenchyma or fundamental tissue, par. ; l.l., lateral lines.

39. The Roots of the Bracken.—The true roots of the fern are thin and thread-like, and arise from the underground stem, with which they are closely related in structure. From the epidermic cells arise very fine processes termed **root-hairs** (pars. 30 and 45). The apex of the rootlets is covered with several layers of cells, forming a **root-cap** (par. 32), beneath which is the true growing point. The function of the root-hairs and rootlets is to absorb the water in the soil. This water contains in solution a number of inorganic compounds, which serve as food for the plant (par. 46).

40. The Fronds of the Bracken.—The fronds arise at points on the rhizome termed **nodes**, the spaces between such positions of origin being called **internodes** (Fig. 64). The stalk or rachis of a frond is at first beneath the ground, and dark in colour like the rhizome. Its lower part to the point where it branches is sometimes termed the **stipes**, and is downy while young. When a frond is fully unfolded, in June, the green rachis is seen to branch once or twice, each branch bearing a triangular leaf-like division called a **pinna**. The pinnæ stand opposite in pairs, and break up into other pinnæ, the smallest subdivisions being called **pinnules**. Each pinnule has a midvein, which gives off lateral veinlets that extend to the margin, where they meet another veinlet that runs round the margin (Fig. 67).

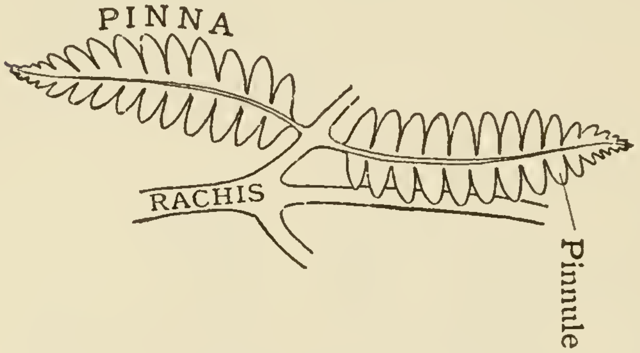

Fig. 66.—Portion of rachis with two pinnæ showing pinnule.

The rachis and its branches have the same general structure as the stem, as it consists of a mass of soft parenchyma tissue covered externally with epidermis, and strengthened internally by longitudinal vascular bundles that are continuous with those of the undergrown stem. The green blade of the frond with its pinnules has a similar structure and function to the leaf of a flowering plant (pars. 15 and 52). There is a thin epidermis with stomata, and between the upper and lower epidermis the soft leaf parenchyma, traversed by the vascular bundle forming the veinlets. In the autumn there is found, situated all round the margin of many pinnules, a brown linear patch of structures covered with a thin covering, formed by an inturning of the upper epidermis of the leaf called an **indusium**. This patch, which was green in the early part of the year, is termed a **sorus**, and the structures of which it consists rest on a cushion of tissue, the **placenta**, that lies over the marginal vein of the pinnule.

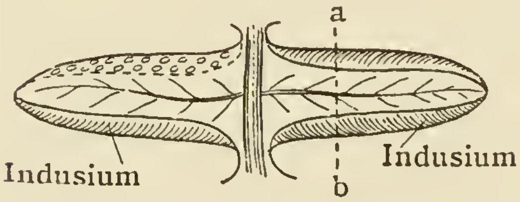

Fig. 67.—Two pinnules of bracken under surface, indusium removed on one edge to show sporangia beneath.

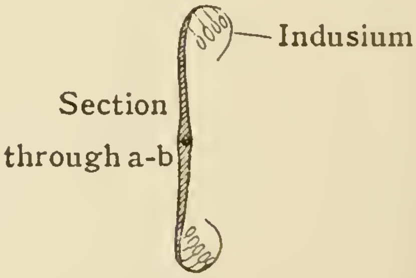

Fig. 68.—Section of a pinnule to show indusium and stalked sporangia.

On examining a sorus with a good lens, or under a low power of the microscope, the sorus is found to consist of a collection of small ovoid bodies called spore-cases, or **sporangia**, each

sporangium being borne on a slender stalk. A sorus is thus a group of sporangia, and a sporangium is a stalked flask or capsule. The ovoid head of the sporangium is really a capsule containing minute reproductive bodies termed **spores.** It has an **annulus** or ring round two-thirds of its circumference. When fully ripe, the annulus contracts, and as it does so it bursts the thin part of the sporangium and throws out the spores, which appear as a brown powder. To see the bursting of the sporangia, place some ripe ones on a glass plate, and gently warm with a spirit-lamp. On watching with the lens, the shortening of the annulus and the sudden bursting of the capsule with ejection of the spores may be readily observed.

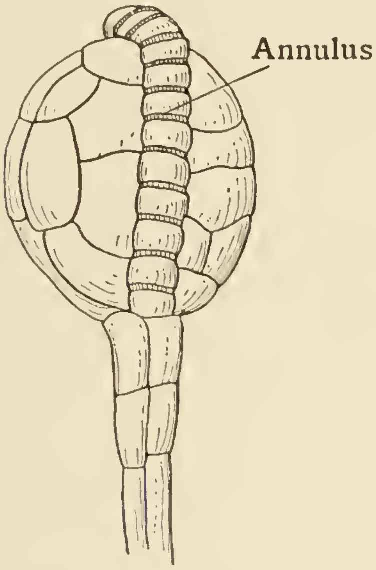

FIG. 69.—A sporangium seen from behind (magnified).

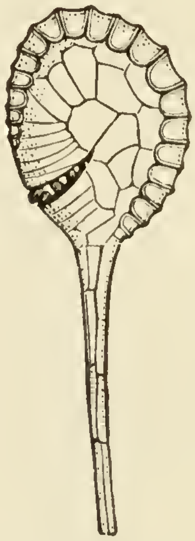

FIG. 70.—Sporangium (side view) bursting to let out the spores (magnified).

41. Reproduction of the Fern.—Ferns do not bear sexual organs, but spores. Spores are reproductive bodies, but they are not like the seeds of the higher flowering plants, for they have not been produced by the action of a pollen grain on an ovule, and do not contain an embryo. Further, when the spore of a fern germinates, it does not produce another fern like the plant on which it grew, but a small, flat, green, heart-shaped plant without stem or leaves, called a **prothallus** or **prothallium.** This prothallus has a few root-hairs passing from its under surface, and in a short time produces two kinds of small bodies, and from these arises a true fern plant. The generations thus run: fern, prothallus, fern, prothallus, fern, and so on, alternately.

The structure developed from a fern spore, and called a **prothallus**, is a small heart-shaped flat mass of green tissue about a quarter of an inch across. It consists of a mass of minute cells containing chlorophyll, the cells being in a single layer at and near the margin, but several layers thick in the central part, called **the cushion.** From the under surface unicellular root-hairs pass down into the soil, from which they absorb nutriment. By means of the chlorophyll in the cells the prothallus can obtain carbon from the carbon dioxide in the air, and by means of its root-hairs, or rhizoids, it can obtain nutriment from the soil. A prothallus is thus a distinct self-supporting plant.

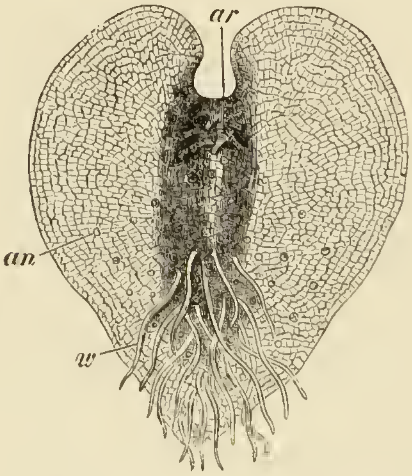

FIG. 71.—Under surface of a prothallus enlarged about four times. *w*, root-hairs; *ar*, archegonia; *an*, antheridia. (Wettstein.)

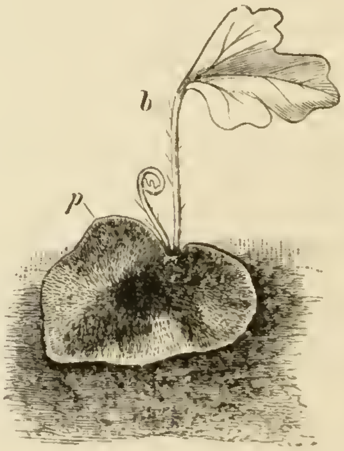

FIG. 72.—A prothallus. *p*, with a young fern-plant, *b*, arising from it — seen from above. (Wettstein.)

On the under surface of a prothallus are developed two kinds of small bodies forming distinct sexual organs, **antheridia**, or male organs among the root-hairs near the pointed base, and **archegonia**, or female organs on the cushion near the notched apex (Fig. 71). Each antheridium is a small spherical capsule, which gives rise to male cells called antherozoids. Each archegonium is a small flask-shaped organ containing a nucleated mass of protoplasm called the **oosphere**, or **egg-cell.** When an antheridium is ripe it sets free antherozoids, which move about in water, and at last enter an archegonium on the same or other prothallus, when it fertilizes the egg-cell. From the fertilized egg-cell there arises by growth and subdivision a tiny fern rhizome with rootlets, from which a frond soon springs (Figs. 72, 73). The young fern plant thus produced is attached for a short time to the under surface of the prothallus, as the prothallus is at first drawn upon for food. But a prothallus has only a short life, soon withering away, and the young fern becomes capable of its own support, at last reproducing the parent fern.

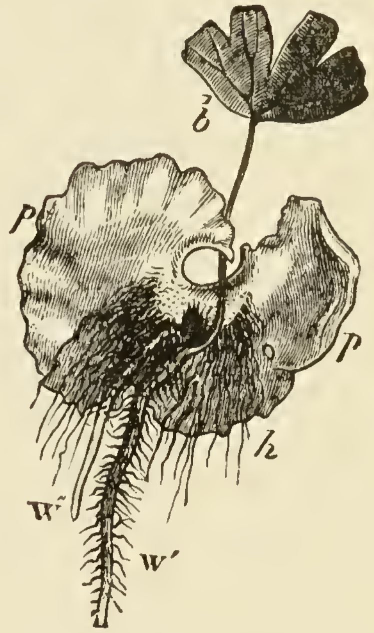

Fig. 73.—Prothallus, *p*, of maidenhair fern seen from below, showing the young plant developed from the fertilized central cell of the archegonium. *b*, first leaf; *w′*, *w″*, roots; *h*, root-hairs of prothallium (× 3). (After Sachs.)

The cycle of events just set forth, in which we have (*a*) a fern-organism which produces (*b*) a prothallus organism from which (*c*) a fern-organism like *a* arises, is often spoken of as "an alternation of generations." "The process is further remarkable for the working together of two types of reproduction, sexual and asexual. The essence of sexual generation is that a cell—the ovum or egg-cell—is fertilized by a male cell, which unites or melts up with it, and the fertilized egg-cell thus becomes capable of developing into an embryo or young plant. The essence of asexual reproduction is that the parent produces a cell without being stimulated by a process of fertilization."[1]

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[1] "The Elements of Botany," by Francis Darwin, p. 119.

In the case of the ferns, it is the prothallus which bears an egg-cell, and when this is fertilized by a male cell, it develops into a fern. The fern then produces without a sexual process the reproductive bodies called spores, and from a spore a prothallus results. Instead, therefore, of there being, as in higher plants and animals, a regular series of sexually produced generations, there are alternate sexual and asexual generations.

Experiments.—Various experiments have been suggested to the reader in the foregoing paragraphs. Dig up two or three rhizomes. Find the growing point, the young fronds in various stages beneath the soil (they often take two years before they begin to unfold above the surface), the frond of the present year, the bases of the old fronds. Make a section of a rhizome and examine the appearance, picking out the bands of sclerenchyma and the closed vascular bundles. Note the root-hairs both on the thin fibrous roots and on the rhizome. Obtain a fruit-bearing pinnule and note the sori. Scrape off some of the sporangia and examine with a good lens. Note their form and structure under a microscope, if possible. By pressing on sporangia beneath a cover glass, they may be burst. With a high power of the microscope ($\frac{1}{6}$ inch) the separate spores may be seen.

To obtain prothalli, scatter spores from some fern on damp earth, or on a piece of soft brick that has been well boiled to kill any organisms on it. Keep the spores moist and out of direct sunlight. This may be done by watering the soil, or by keeping the brick in a saucer of water. The brick may be kept covered over with a bell jar in a dark corner of a living room. After some weeks, small green flat bodies, each of which is a prothallus produced by the germination of a spore, can be noticed. Pick up with a needle a prothallus, and examine first with the unaided eye and then with a low power of the microscope. Note its root-hairs. The antheridia are found as minute swellings on the thinner part of the prothallus, and the archegonia on a thicker part (the cushion), among the rootlets. The minute structure of an antheridium or of an archegonium and the development of a prothallus can only be made out with a high power of the microscope.

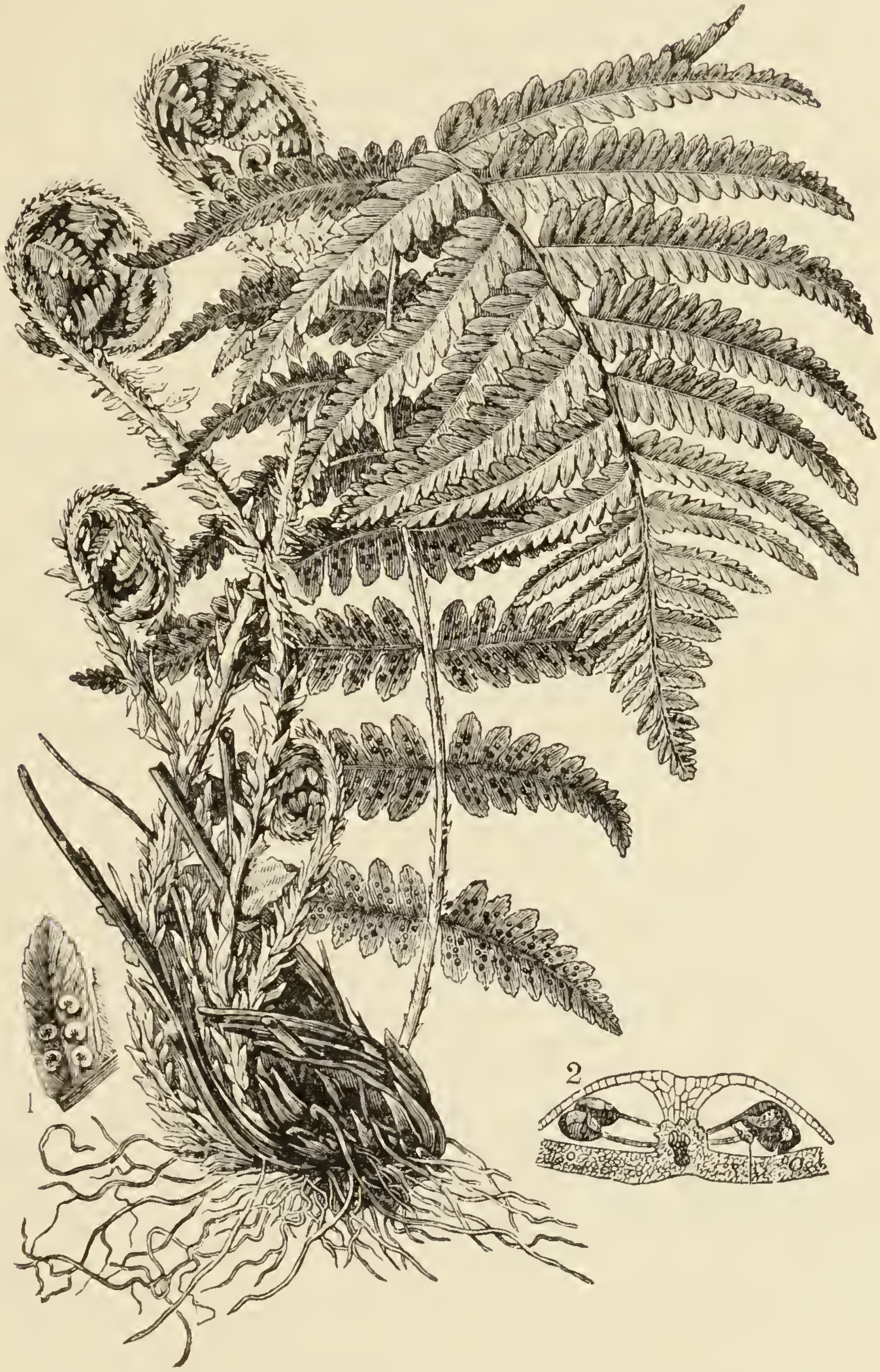

FIG. 74.—The male fern, showing the form of a frond and the mode in which young fronds are rolled up curled upon themselves. At 1 is shown five sori, each covered with an indusium. At 2 a cross-section through a sorus, showing the attached sporangia beneath the indusium.

42. The Common Male Fern.—This fern, known also as the male shield fern, is so abundant and easily met with that a short description may be useful to the student. It has a short thick ascending rhizome, covered with the withered bases of former fronds and many fibrous rootlets. The fronds grow in a circular clump from the upturned end of the rhizome near the apex, and as they unfold from their spiral coils in spring the fern looks very pretty. A fully formed frond is of a broad lanceolate shape, and is often bipinnate, though the pinnæ are not always clearly divided into pinnules. The leaf-stalk (stipes and rachis) is covered for about a third of its length with pale brown scales.

A wavy mid-vein passes from the rachis into each pinnule or pinnatifid division, and from this mid-vein veins and veinlets pass towards the margin. The sori form round clusters on the under surface of the pinnules, the clusters being arranged in two rows (Fig. 74, 1). Each sorus is covered by a kidney-shaped indusium, which is attached to a veinlet at the point where the stalks of the sporangia are placed (Fig. 74, 2). As the season progresses, the indusium withers up and leaves the sporangia exposed. Though differently arranged on the pinnule, the sporangia have a structure similar to those found on the bracken fern. When ripe, the annulus of a sporangium contracts and causes the opposite thinner part of the capsule to burst, thus setting free the spores. The minute spores of ferns are easily scattered by the wind, and when they fall upon a suitable soil germinate. Each spore gives rise to a prothallus, and from this there arises, in the way already described, the particular parent fern.

CHAPTER VII.

THE NUTRITION OF PLANTS THROUGH THE ROOTS.

43. Chemical Composition of a Plant.—A bean or any other seed consists of water and certain solid substances. A whole plant also consists of water and certain solid substances, together with some included gases. If we heat a plant to a temperature a little above that of boiling water (100° C.; 212° F.), the water is driven off in the form of water-vapour, and the solid matter is left behind. This solid matter consists of organic matter and a small quantity of mineral matter. On heating the solid matter to a still higher temperature in the air, some of the solid organic substances are decomposed, and some enter into composition with the oxygen of the air, so that various gases, such as carbon dioxide and ammonia, pass off. But however high the temperature, there always remains a small quantity of incombustible mineral matter termed the **ash** of the plant. By analysis of the gases and the remaining ash, chemists have shown that plants always contain the following elements: *carbon*, *hydrogen*, *oxygen*, *nitrogen*, *sulphur*, *phosphorus*, *potassium*, *magnesium*, *calcium*, *sodium*, and *iron*. These elements do not exist as elements in the plant, but they are combined to form the various compounds of which a plant is composed. By comparing the weight of a seed with that of the grown-up plant springing from it, we find that there is a greater weight of water and of the various solid substances in the plant than in the seed. Now, as increased weight indicates increased quantity of matter, the plant during its growth must have obtained matter from outside, since matter cannot be created out of nothing. From what source or sources does the plant obtain the matter which feeds it during growth, so as to enable it to increase in weight? Evidently either from the air or the soil, or from both, for these are the only two parts of the outside world that it comes into contact with. It is, therefore, of importance to learn the relation of a plant to the air and to the soil.

44. Chemical Composition of Air and Soil.—The **air**, as we have already learnt, consists of a mixture of free nitrogen, free oxygen, a small quantity of carbon dioxide, and a varying amount of water-vapour, with traces of ammonia and other gases. It is clear from this that the air alone cannot supply all that a plant needs, for, as just shown, there are certain elements in plant substances that do not exist in the air at all.

Soil is made up of small mineral particles, some soluble and some insoluble in water, together with decaying organic matter. Small interspaces between the particles are occupied by air, and there is nearly always some water present. This is not pure water, but water which contains in solution the various soluble compounds of the soil. These soluble compounds contain nearly all the elements required by the plant except carbon. Now, the carbon compounds of a plant form a large and important part, so that it is now clear that the carbon required by a plant can only be obtained from the carbon dioxide of the air.

Experiment.—Collect water passed through some soil in a flower-pot. Filter it to remove suspended matter, and then evaporate the clear solution in an evaporating-dish. A residue is left, showing that soluble matter was taken up from the soil by the water that has passed through it.

Numerous experiments, in fact, go to prove that the food required for the nutrition of plants is provided by the water and the soluble salts in the soil, and by the carbon dioxide in the air. With the help of this food the plant is able to grow, for it possesses the power of changing these inorganic substances into the protoplasm and other organic matters that form its body. In other words, plants are able to transform inorganic materials into organic substances, which are either stored for future use or built up into the living substance of the plant.

This is essentially different from the process of nutrition in animals, for animals can only live on organic matter supplied by plants or by other animals.

As plants possess no openings that correspond to the mouths of animals, it is necessary to examine further the nature of the organs by which the plant obtains its food. The organs are the roots in the soil and the green leaves in the air. We proceed to consider the roots first.

45. The Roots are the Water-absorbing Organs of Plants.—It is a matter of common observation that plants must be kept supplied with water, else they soon wilt or become soft, wither, cease growing, and die. This observation indicates that plants must both absorb and give off water.

Cut plants soon wither, because they give off water through the leaves and no fresh water is taken in. Although we can restore wilted flowers or small branches for a time by putting the cut ends in water, especially if part of the stem is cut off under water, yet such flowers or branches do not continue to grow. Again, if we supply water to the stem and leaves of a plant flowering in a pot, and yet keep the soil dry, the plant, though somewhat revived for a short time, withers and dies. It is thus clear that the shoot, *i.e.* the stem and leaves, are not able to absorb all the water that is needed. If, however, we keep the roots of a plant fixed in the soil and moist, it grows and thrives. The root, therefore, must be the water-absorbing organ, and the water is in ordinary cases obtained from the soil.

Experiment.—To show that roots absorb water, take a seedling and fit it into a hole in the cork of a glass bottle in such a way that the roots dip into the water, and so that the water cannot evaporate into the air. Note the level of the water in the flask, and observe that after a time the level of the water falls. By arranging a tube bent at right angles so that one arm passes through the cork into the water, while the horizontal arm is provided with a graduated paper scale, it is even possible to estimate roughly the rate at which the roots are sucking in the water, by finding the amount of water included between two successive graduations.

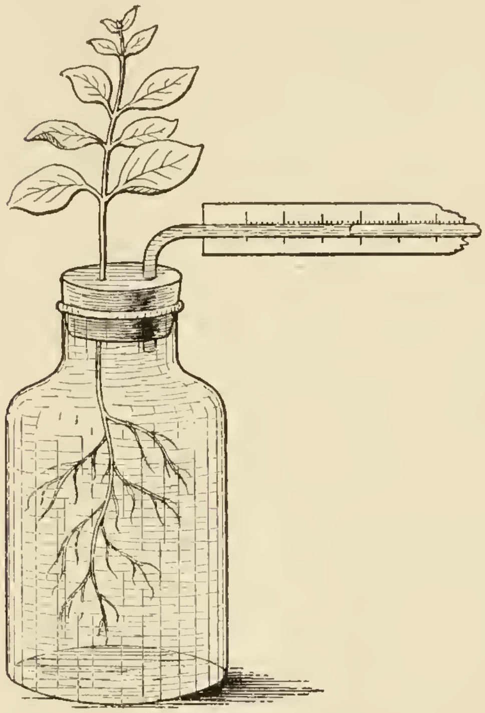

FIG. 75.—Illustrating the absorption of water by the roots of a plant, and the mode of measuring the amount absorbed.

It is only the terminal portions of the root and rootlets, however, that absorb water. The part of a root or rootlet a short distance behind the tip is the part which absorbs, and this part of a root is supplied with numerous fine root-hairs. The fine rootlets and root-hairs penetrate between the particles of soil,[1] and often adhere so closely to these particles that, when the plant is drawn out of the soil, a large quantity of the particles remain attached to the hairs. That it is the root-hairs and the young terminal parts of roots that perform the work of absorption, is shown by the fact that if these parts be cut off the plant withers, and may even die. It can also be shown by arranging seedling plants so that only parts of the roots above the root-hairs get water. Such seedlings soon wither.

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[1] The root-hairs are really living cells, whose special function is to absorb the thin film of water on the particles of soil together with the mineral matter dissolved in this water. Now, the protoplasm of all living cells requires oxygen from the air, and it may therefore be easily understood how too much water may drive out all the air from the soil, and thus prevent the root-hairs from performing their functions with advantage to the plant. Hence badly drained soils are injurious to vegetable life. On the other hand, a soil too dry fails to supply the root-hairs with the water needed, and they perish from drought.

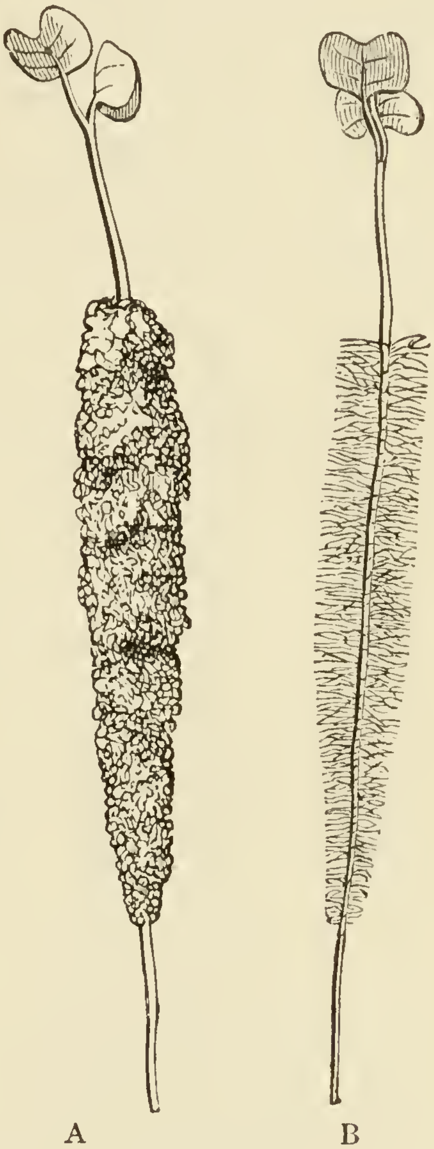

Fig. 76.—Seedlings of white mustard. A, after removal from a soil of fine sand with the particles adhering to the root-hairs. B, after removal of sand by washing (in older roots the root-hairs are only found at a short distance behind the growing-point).

46. Roots not only absorb Water, but the Inorganic Salts dissolved in the Water.—It is clear, from what has been said of the composition of plants, that they require, besides water, such substances as carbon, nitrogen, potassium, phosphorus, calcium, magnesium, and iron. The carbon, as we shall presently prove, is obtained by the aid of the leaves from the carbon dioxide of the air, and not from any carbon compound that may be in the soil. It is true that nitrogen is also present in the air, but plants, with few exceptions, cannot make use of atmospheric nitrogen. Hence it appears that, with the exception of carbon, the food material of plants must be obtained from the soil. How, then, does the plant get these substances? The elements above named as requisite are not present as elements in soil, but certain compounds of these elements known as salts by the chemist are in the soil. But these inorganic salts of the soil must be in solution before they can be absorbed, for plants cannot take in any solid matter.

Experiment.—Take two similar small plants with uninjured roots, and put one in water in which a little of the soluble powder called eosin has been dissolved. This makes the water red. Put the other plant in water in which insoluble powdered carmine has been stirred. The eosin in solution will be absorbed, as can be seen on cutting the stem across after a short time and noticing that it is coloured. There is no coloration of the stem of the plant placed in the water containing the carmine. Plants, in fact, can only absorb substances when in solution.

The absorption of the watery solutions of inorganic substances required by plants from the soil can be illustrated experimentally by what is known as "water culture." Various solutions of inorganic salts are made containing those elements which enter into the composition of plants, and by experimenting with these, it has been found which is the **culture solution** that is best adapted for the nutrition of plants through the roots. A complete and satisfactory water-culture solution containing all that is needed by green plants, except the carbon, which is obtained from the carbon dioxide of the air, is the following :—

Potassium nitrate	1 gramme.
Sodium chloride	½ ,,
Calcium sulphate	½ ,,
Magnesium sulphate	½ ,,
Calcium phosphate	½ ,,
Water	1 litre.

A few drops of dilute solution of iron chloride must also be added.

It should be noted that the quantity of the various salts is very small compared with the amount of water (1000 c. cms. of water = 1000 grams), and that the solution formed is therefore a very weak solution.

To carry out experiments with culture solutions, wide-mouthed bottles with suitable corks are very useful. A bean, pea, maize, or other seed is first made to germinate in damp sawdust until the radicle and plumule have got a good start, so that the seedling can be handled. A notch is then cut in the cork, and the plant so placed in it that the root hangs down into the culture solution, while the stem passes upwards into the air. The plant may be kept in position by supporting the stem in the cork with cotton-wool. The sides of the vessel should be covered with black paper to keep the light from the roots, and the solution changed about once a week. By taking proper precautions, a plant grown in such a complete culture solution as that given above may be brought to maturity and ripe seeds obtained from it.

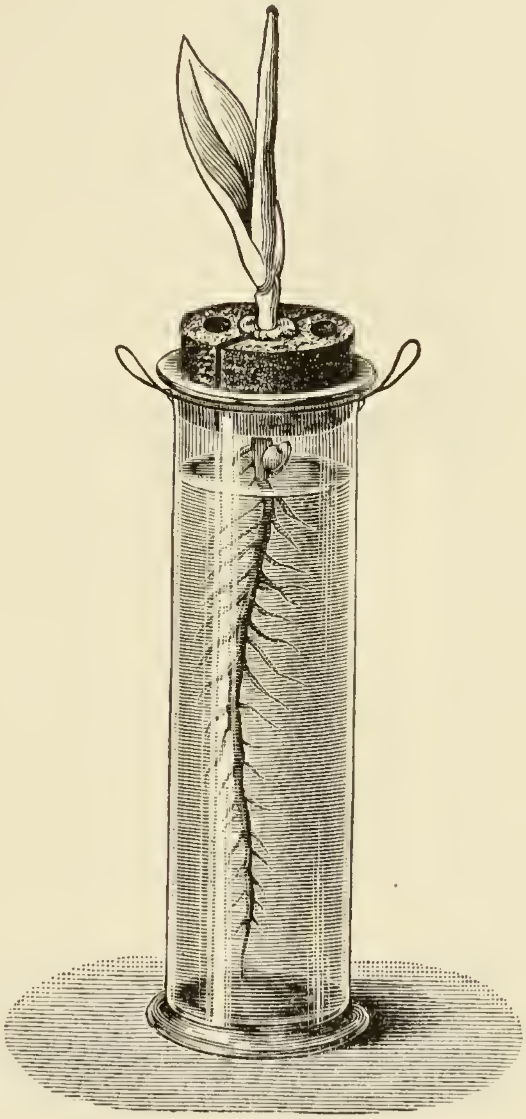

FIG. 77.—Maize seedling growing in a culture solution.

Instead of growing the plant in a bottle as above, it may be grown in white insoluble sand or ground tile kept moist with the culture solution. In either case, the only soluble matter is that supplied by the culture solution, the sand or tile-powder being quite innutritious. If any of the substances necessary for a complete nutrient solution be omitted, the plant will not thrive, and may even die. Without some iron salt in solution, for example, the leaves will not become green. If nitrogen in the form of a soluble nitrate or potassium in the form of a soluble potassium salt be omitted, the plant remains stunted, and thrives badly. A phosphate is also necessary, for if omitted growth soon ceases. The sodium chloride, however, although found in all plants, may be left out, and the plant will continue to grow.

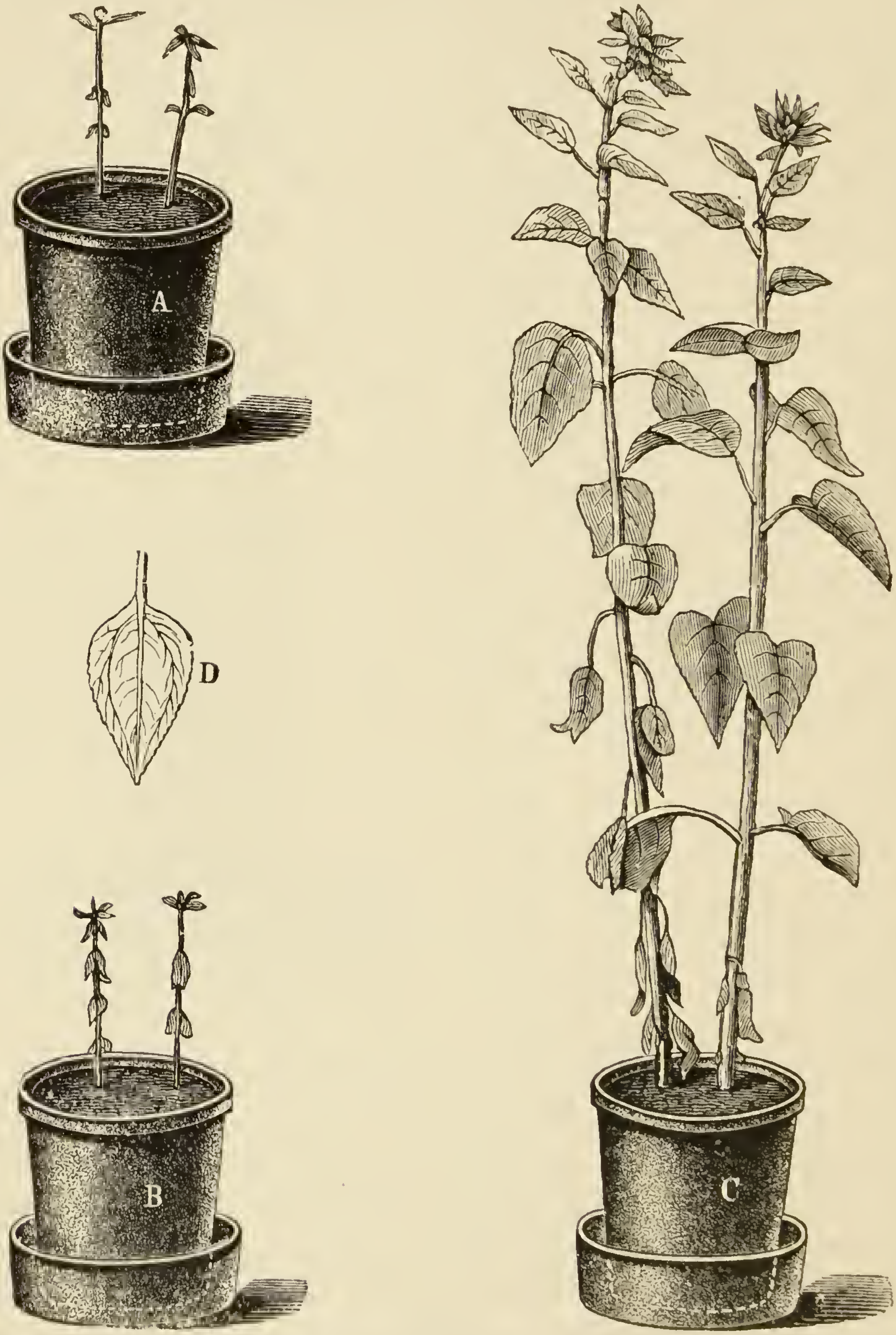

Fig. 78.—Development of the dwarf sunflower. A, in soil consisting of insoluble sand and crushed tile kept moist with pure water; B, in similar soil, with the addition of some calcium phosphate, potassium carbonate, and plant ash; C, in a similar soil to B, but with the addition of potassium nitrate; D, a leaf of the garden plant. The experiment clearly shows that the plant needs nitrogen in a soluble form (there is no nitrogen compound in plant ash), and that atmospheric nitrogen cannot be made use of by the plant. As no carbon compound is in the solution, the plant must derive its carbon from the air (par. 52).

These facts are well illustrated by the experiment illustrated in Fig. 78, where sunflowers are grown for the same time under the conditions stated beneath the figure.

47. The Course of the Current of Water and Dissolved Salts up the Stem to the Leaves.—As the roots of a plant continue to absorb water day after day, and, as we shall shortly see, the leaves give off water day after day in the form of water-vapour, it is clear that the water absorbed by the roots must pass upwards to the leaves. The dissolved mineral matter must also pass upwards, as such matter absorbed only by roots is found in the stem and leaves. By what path does the water ascend? Experiments have shown that the water passes up the vascular bundles of root, stem, and leaves—that is, through the strands that form the woody portion of a plant.

Experiment.—Place the cut stem of a herbaceous plant, like the bean plant, in a weak solution of eosin or red ink, and allow the plant to remain in the sunlight for some time.[1] After an hour cut sections across the stem and notice with a lens that the vascular strands are stained, while the rest of the tissue is colourless, for the liquid is not absorbed through the outside, but at the cut end. The solution will also be found in the leaf-stalks and the veins of the leaves.

A similar experiment may be made with the flower-stalk of a crocus, narcissus, etc., when the water path along the thin vascular bundles in the leaves and petals will become stained.

Experiment.—Take a small branch with leaves, and cut off a ring of outer tissue or bark near the middle. Place the lower part of the branch beneath the cut in water, and notice that the leaves do not wither, but still obtain water. Water, therefore, does not travel upwards through the bark.

48. The Causes of Water Absorption and Transference.—We have learnt that water and watery solutions are absorbed by root-hairs and the young parts of the roots near those hairs. But the question remains, how does this absorption take place? The root-hairs and the roots consist of cells with a cell-wall, and the most powerful microscope shows no holes of any kind in the membrane forming the cell-walls.

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[1] The end of the stem should be cut under water to prevent air getting into the conducting channels.

Absorption of water by the root-cells, and the passing on of the water from cell to cell, is largely a process of diffusion called **osmosis**. The nature of the process may be illustrated by the following experiments :—

Experiment.—Take a small jar or vial and fill with a solution of sugar made by dissolving two teaspoonfuls in a cup of water. Tie over the mouth of the jar thus filled a piece of membrane obtained from a dry bladder, first wetting the membrane. Now sink the vial in a vessel of fresh water, and allow it to remain several hours. Notice that the membrane swells up, and, instead of lying straight across, bulges out, owing to pressure from the inside. This internal pressure is rendered more evident by the spurting out of fluid when the membrane is pricked. The sugar solution in the vessel has attracted the water outside through the bladder, and set up within the vessel an internal pressure.

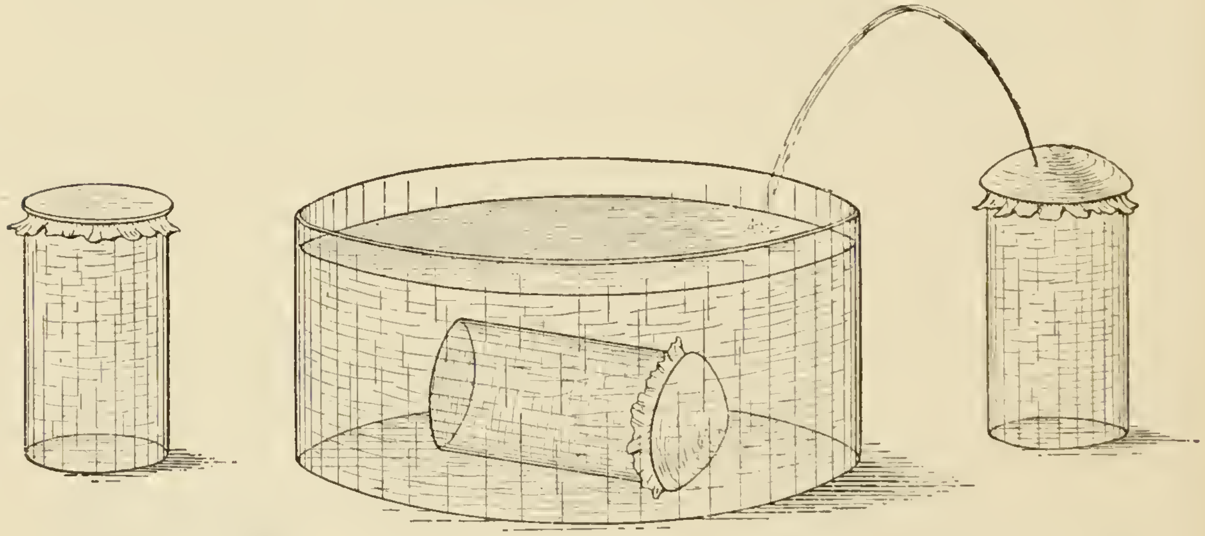

FIG. 79.—Experiments to illustrate the nature of osmosis and osmotic pressure.

A similar thing will happen if we use a solution of nitre, copper sulphate, and many other substances, and it is found generally that when two such liquids of different densities are separated by a membrane, water will pass through the membrane into the stronger solution. The diffusion or passage of liquids through membranes in which there are no visible openings is termed **osmosis**, and the internal pressure set up is called osmotic pressure.

Experiment.—Take a thistle funnel and tie firmly over the end a piece of bladder membrane. Pour into the inverted funnel a strong sugar or nitre solution, so as to fill the cup and a small part of the stem. Sink the inverted funnel in the water, so that at the beginning of the experiment the level of the liquid in the funnel and the outside vessel is the same. Note that the level of the water in the tube rises, being drawn through the membrane and pushed upwards against the force of gravity.

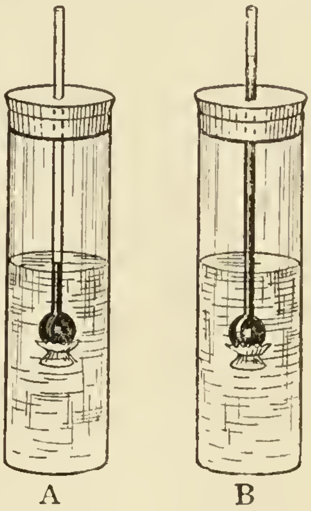

FIG. 80.—Illustrating osmosis and how osmotic pressure causes the ascent of a liquid against gravity. A, the funnel when first put into the liquid; B, the funnel after the water has risen above the level of that in the cylinder.

We have now some idea of how root-cells absorb the film of water covering particles of soil through the membranes formed by the cell-wall, for these cells contain cell-sap, which is a watery solution somewhat stronger than the watery solution in the soil. In a similar way the liquid is passed on from cell to cell, though the process is probably aided and modified by the living protoplasm in the cell. We further see how this absorptive power at the root renders the cells turgid, and sets up what is termed **root-pressure**—a force which causes an upward movement of liquid along the stem. This upward movement is manifested by an appearance known as "bleeding" when a stem such as the vine is cut across, especially in spring, when the upward water-current is most active. Sap is then seen to flow out from the cut end of the stem that is still in connection with the root.

Capillary attraction, or the rise of liquids in fine tubes, due to forces of cohesion and adhesion, also assists the upward movement of liquid in the stems of plants. The upward movement of water in a stem is also due in part to another cause called **transpiration**, a term which is used for the giving off of water-vapour by the leaves of a plant. This loss of water from leaves goes on continuously. Root-pressure, capillarity, and transpiration, therefore, are causes of the upward current of water in the stems and leaves of the plant, though these causes are probably aided by the activity of the living cells.

49. Transpiration.—When we learn that an actively growing plant often absorbs in a few days water equal to several times the weight and volume of the whole plant, it is plain that only a portion of this water can be used as food, and that the rest must be given off. Leaves are, in fact, frequently transpiring or giving off water in the form of vapour, and **the loss of water from the leaves of plants is called transpiration.** A great quantity of water is taken up by plants in order to obtain the small amount of mineral food in solution, and the result of transpiration is that the excess of water taken up by the roots is sent out into the air through the stomata of the leaves, and the solution of the various mineral salts in the plant cells in all parts thus becomes stronger or more concentrated. This process of transpiration no doubt aids root-pressure in lifting the water through the stem and up into the leaves. Various circumstances influence the amount and rate of transpiration. It is most active under the influence of light and warmth, and when the atmosphere is somewhat dry. At night the stomata close, and there is little transpiration.

Experiment.—Take a plant growing in a pot, and cover the pot and soil with flexible oil-cloth, tying the cloth round the stem so as to prevent evaporation from the pot and soil. Place the plant under a bell jar, and leave for some hours. The water-vapour given off begins to condense, after some time, on the inside of the cold jar, forming tiny drops, and at last water may be seen trickling down the sides of the jar. This water can have only come from the living plant. It comes, in fact, from the leaves. If we place a bunch of living leaves without any free water on them under the dry jar, we shall find, in less than an hour, that the inside of the jar is bedewed with moisture.

Transpiration takes place chiefly from the under side of the leaves of most plants, as it is on the under side that the stomata are usually most abundant. This can be shown by using dry filter-paper that has been dipped in a solution of cobalt chloride—such paper is very sensitive to moisture. A solution of cobalt chloride is red, and so is the paper dipped in it at first. When the paper becomes dry, it is blue. Place on a small sheet of glass a piece of dry cobalt paper and a geranium leaf, with the under side downwards on the paper. On the upper side of the leaf place another piece of dry cobalt paper, and over this another sheet of glass. A light weight will keep the layers in contact. After a quarter of an hour, it will be found that the cobalt paper in contact with the under surface of the leaf is much redder than the piece in contact with the upper surface of the leaf. There is, therefore, a greater loss of water from the under side of the leaf than from the upper side.

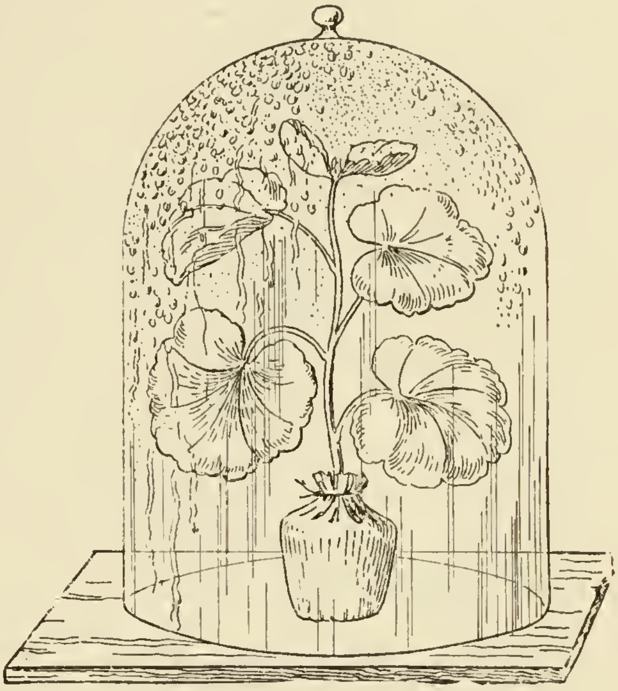

Fig. 81.—Experiment illustrating the transpiration of water by the leaves of a living plant.

50. Distribution of the Absorbed Fluid through the Plant.—The fluid matter absorbed by the roots (water and dissolved mineral salts) is made to ascend the stem by the causes just described, and passing, as before stated (par. 47), along the wood tissue of the fibro-vascular bundles, it reaches all parts of the leaves along the numerous veins distributed in these organs. In the cells of the leaves and other green parts this crude sap, as the fluid may be called, undergoes a series of changes under the influence of the air and light, by which it becomes elaborated and adapted for the uses of the plant. One of these changes will result from the process of transpiration already described, for this loss of water will evidently cause the crude sap to become more concentrated. But the chief change results from the absorption and decomposition of carbon dioxide by the leaves, for in this process carbon is added to the sap, and carbohydrates like sugar and starch are produced. Other organic products which are required for the formation of new tissue and for various secretions are then worked up or elaborated.

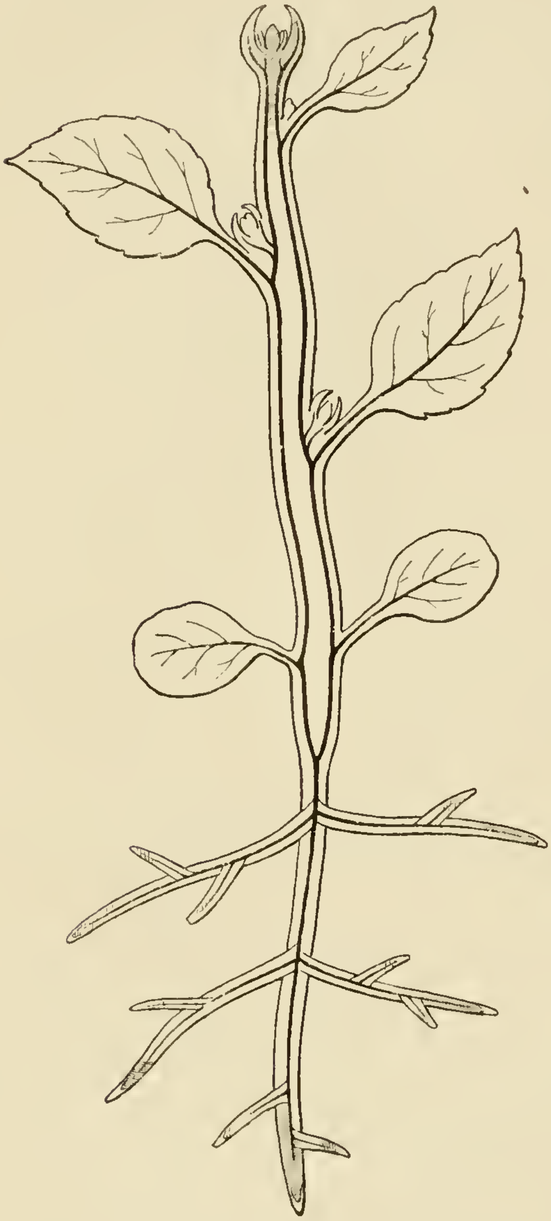

FIG. 82.—Diagrammatic section of a young dicotyledonous plant, showing by lines the arrangement and distribution of the fibro-vascular system along which the sap travels.

The materials formed in the leaves are transferred to other parts of the plants, the descent of the elaborated sap taking place along the vascular tissue of the phloëm or inner bark and the cambium layer. It is from the products thus formed in the plant that the materials are provided for the production of flowers and fruit, for new tissue of all kinds, and for a store of food for future use. We will now proceed to consider the work of the leaves in more detail.

CHAPTER VIII.

THE STRUCTURE AND FUNCTIONS OF GREEN LEAVES.

51. Structure of Leaves.—A large number of leaves consists of two parts—a stalk, or **petiole**, and a blade, or **lamina.** The base of the stalk may be swollen out where it is attached to the stem, or it may have leaf-like appendages termed **stipules** (Fig. 13). In many cases there is no petiole, or leaf-stalk. The blade is the most important part of the leaf. The shape of the blade varies much in different plants. In some cases the leaf-blade is simple; in others it appears to be broken up into distinct leaflets, and is then termed **compound** (Fig. 118).

The substance of a leaf presents to the unaided eye two or three kinds of substance: (1) a number of veins or strings of stout material which start from a median midrib or from the base of the leaf, and then divide or subdivide in all parts of the blade to form a fine network; these veins consist of vascular tissue, and are conducting channels, communicating with similar tissue in the leaf-stalk and stem (Fig. 83); and (2) a softer substance filling up the spaces between the veins of the leaf. Covering the whole of each surface of the leaf there is also (3) a thin skin called the **epidermis,** which consists of a single layer of cells on each side.

A highly magnified surface view of a leaf shows the outlines of the epidermal cells and the small openings termed

stomata formed by two curved sausage-shaped cells (Fig. 36). A thin section across a flat leaf shows that a stoma, or pore, on the surface leads into an air-space inside the leaf-tissue. Such a section is shown in Fig. 84, where the reader is supposed to be looking at the cut edge of the leaf when magnified.

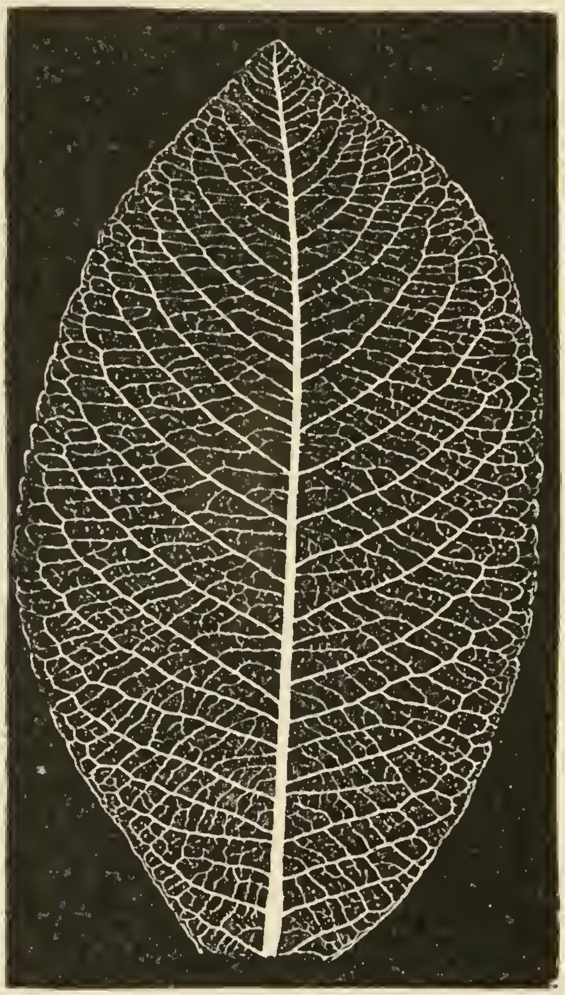

Fig. 83.—The complete network of veins transversing the cellular tissue of a willow leaf.

The stomata, in fact, serve for the escape of water-vapour in the transpiration process, and also take part in the interchange of gases which goes on between the plant and the atmosphere.

The functions of green leaves are in reality three: (1) They are the chief transpiring organs of the plant by which the excess of water taken up by the roots is got rid of in the form of water-vapour through the stomata; (2) they perform the work of taking in carbon dioxide from the air, splitting it up so as to set free the oxygen and retain the carbon, which is combined with some of the water taken up by the roots to form starch or some other carbohydrate; (3) they, in common with other parts of a plant, take in oxygen in the process of respiration. The transpiration by leaves has already been considered and illustrated in connection with the upward movement of the watery solution taken in at the roots (par. 49).

52. Carbon Fixation or Assimilation in Plants.—

Half the dry weight of a plant consists of carbon, and though a very little of this may be obtained from decaying organic matter in the soil, by far the greater part is obtained from the carbon dioxide of the air. Indeed, in the method of water-culture (par. 46), there is no other source from which the plant can obtain carbon. How is this effected?

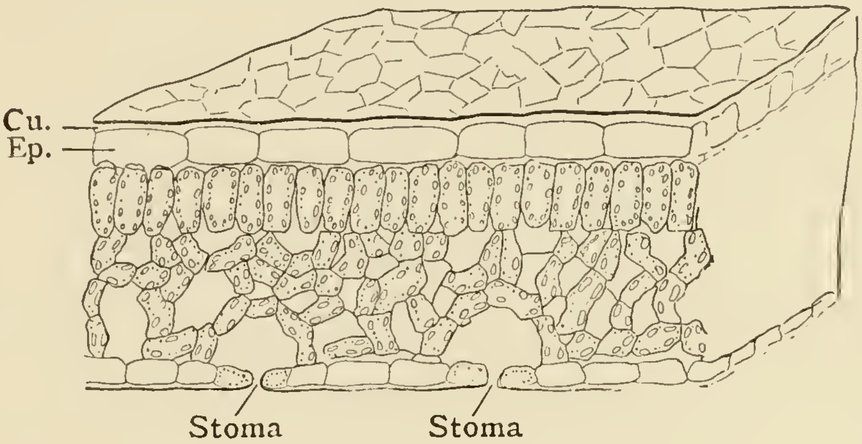

FIG. 84.—Section of a leaf to illustrate its internal structure. Note the upper and lower epidermis, with the thickening of the outer cell walls of the epidermis (Cu., cuticle). Two stomata are seen in the lower epidermis with their guard cells. Between the upper and lower epidermis are air-spaces and cells with chlorophyll granules, the cells being more numerous and more closely packed like a palisade near the upper epidermis.

Now, numerous experiments go to prove that green leaves exposed to light take in carbon dioxide through the stomata, decompose this compound, retain the carbon for food, and give back the oxygen to the air. The process stops in the dark, for it is the energy derived from the sun's rays which enables the green leaves to do their work. The greenness of the leaves is due to the chlorophyll, or leaf-green, in the small particles found in the cells forming the ground-tissue of the leaves. When we speak, therefore, of the green leaves decomposing carbon dioxide and setting free oxygen, we mean the chlorophyll in the leaves does the work with the aid of sunlight.

Experiment.—Take some leafy water-plant, such as the common pond weed **elodea** or water-cress, and put some sprigs in a bottle of spring water. Such water contains carbon dioxide dissolved in it. Place the water with the plant in the sunlight, and note the bubbles of oxygen that come off, especially through the cut end of the stem. By inserting a glass funnel in the vessel over the plant, and slipping a test-tube full of water over the stem of the funnel, the escaping gas may be collected. This gas can be proved to consist mainly of oxygen by noting that it rekindles a glowing splinter.

If the above experiment be repeated with boiled water, from which the carbon dioxide is expelled, little or no gas is given off. If the experiment were tried in the dark, little or no gas would be given off. With the roots or other parts of a plant not green we should get no oxygen. If the green leaves were killed by boiling or drying, and then put in the water, no oxygen would be evolved. In short, only the living parts of plants containing the green colouring matter called chlorophyll can obtain carbon from the carbon dioxide of the air, and light is required to supply energy before the chlorophyll can do its work. "Leaf-green and sunbeam fix carbon and set free oxygen." Moreover, research shows that the amount of carbon dioxide taken in and the amount of oxygen given off varies with the number of the stomata in the leaves of a plant, so that the stomata are the organs of the leaves which aid in the interchange of gases between plants and the air. The carbon dioxide passes in

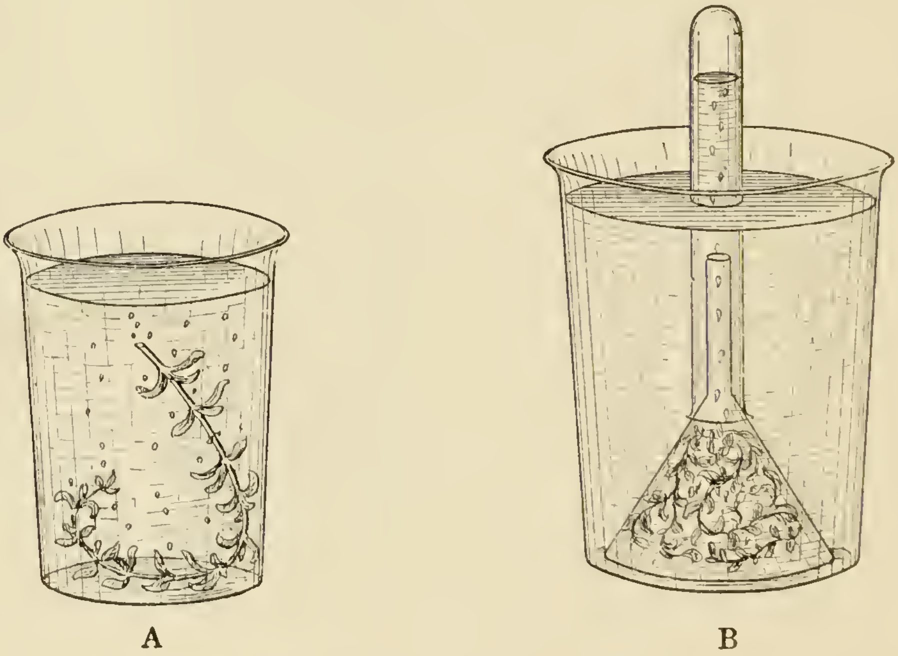

FIG. 85.—Illustrating the decomposition of dissolved carbonic acid and setting free of oxygen by the green leaves of a water-plant. In B the gas is collected in the mode indicated.

at the stomata, and thence into the air-spaces. From these spaces it passes into the cells by osmotic diffusion, and is there decomposed by the chlorophyll.

It must be noted that the above experiment must be performed with water-plants in water containing carbon dioxide in solution. The leaves of land-plants like the bean, the lettuce, the apple, etc., will not do for the experiment as described, although by other experiments it can be shown that all green leaves take in carbon dioxide and give off oxygen. The leaves of land-plants when put in water are not in their natural element, and do not act well. Besides, they always contain within them some air, and have also a thin layer of air on their surfaces. If such leaves are placed in water, and the water is put in the sun, this air expands with the heat and rises as bubbles. Any gas collected, therefore, from the leaves of land-plants would contain a large proportion of the air thus driven off. In the next paragraph the setting free of oxygen from absorbed carbon dioxide is proved in the case of a land-plant.

53. Relations of Green Plants and Burning Bodies to the Atmosphere.—The following instructive experiment is described by Dr. Macdougal in his "Elementary Plant Physiology:" Obtain a large bell-jar with a tubulure (a short open tube) at the top, and a large glass plate upon which it can rest air-tight. In a small block of wood bore a hole in which a candle may be firmly fixed, and then fasten a strip of wood to one side of the block. Glue a strip of sandpaper to the side of the strip next the block, and then place the prepared block on the glass plate so that the strip of sandpaper is near the centre. Place a growing plant on the glass plate. In the tubulure of the bell-jar fix a rubber cork, through which a solid glass rod is placed having a match fastened to its lower end, and so arranged as to come opposite the sandpaper. Now light the candle, and place the prepared bell-jar over plant and flame. The circle of the plate on which the bell-jar rests should have been rubbed with vaseline to make it air-tight.

The candle-flame soon begins to grow smaller and dim, and in a minute or two goes out, because while the flame was alight so much oxygen was used and so much carbon dioxide given off that combustion could not continue.

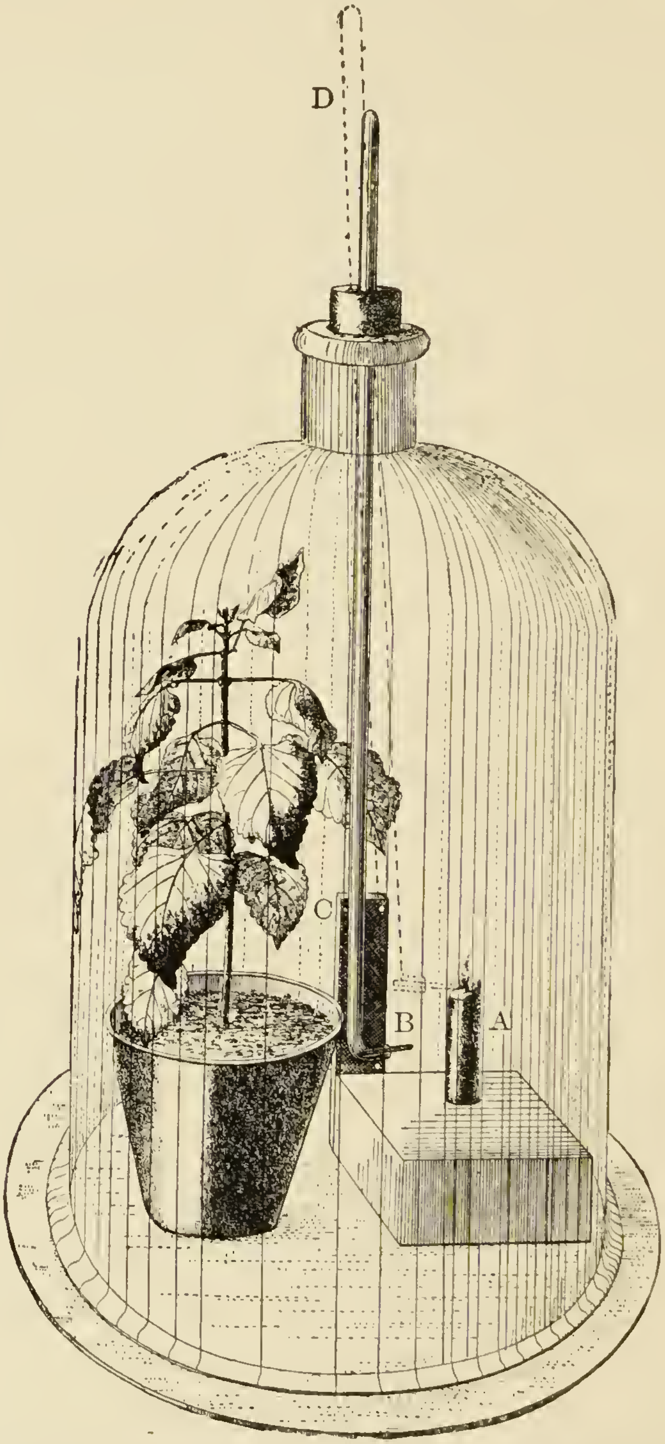

Fig. 86.—Preparation for showing relation of combustion and of plants to atmosphere. A, candle; B, match; C, strip of sandpaper on support; D, glass rod holding match at lower end. The dotted line shows position when applied to candle. (From Macdougal's "Elementary Plant Physiology.")

Keep the whole preparation undisturbed, but allow it to remain in the sunlight a few hours. After this time the match may be lighted by hoisting the rod and by rubbing it against the sandpaper, and then the burning match may be brought to the wick of the candle. The candle is re-lighted and continues to burn for some time, showing that oxygen has been restored to the air in the bell-jar. As the jar has not been raised, this oxygen must have been produced by the plant decomposing some of the carbon dioxide produced by the burning candle, fixing the carbon and setting free the oxygen.

54. Carbon from the Air is used in forming Starch in Green Leaves.—The carbon obtained from the carbon dioxide of the air, together with some of the water brought to the leaves from the roots, undergo certain chemical changes under the influence of sunlight, which result in the formation of starch in the green leaves. The result of the process may be thus represented:

$$\text{Carbon dioxide} + \text{water} = \text{starch} + \text{oxygen}$$

The starch is probably preceded by some kind of sugar ($C_6H_{12}O_6$), and from this the starch-grains ($C_6H_{10}O_5$) are formed by one part of water (H_2O) leaving the sugar. The starch appears as small granules in the leaf-cells, where they may be seen under the microscope. The presence of starch in green leaves that have been exposed to the light may also be shown by the iodine test, for we remember that a solution of iodine turns starch a deep blue (par. 12).

Experiment.—Take, in an afternoon, a few green leaves of a bean plant which has been growing in the light. Put them in boiling water for a minute to kill and fix them in the state then present, and then in warm spirit (alcohol or methylated spirit) for some time. The spirit will remove the green colouring matter, and the leaves become pale. Rinse the leaves, and then place them in a tincture of iodine. They become a deep blue, thus proving the presence of starch in their cells.

On testing the leaves of a plant kept in the dark for a day or two in a similar way, no starch will be found. The starch, in fact, formed during the day is changed into sugar and carried away to other parts of the plant, especially to seeds and tubers, where some of it is again usually reconverted into starch. Some of it, however, is also used by the plant, in conjunction with the dissolved mineral matter obtained from the soil, in order to form new protoplasm in the body of the plant. The need for both the green chlorophyll and light to form starch is well illustrated by the following experiment.

Experiment.—During the day cover a part of a large green leaf attached to a plant in such a way as to shut out the light from that part only. This may be done by pinning two flat corks on each side of the leaf. Now, we know, from the previous experiment, that at this time the whole leaf contains starch. In about a day or two take the leaf in the light, remove the corks, kill it in boiling water, and at once treat it with spirit to remove the colouring-matter of the leaf, and test for starch with iodine. The parts of the leaf that were exposed to the light become deep blue, but the circular part that was covered by the corks does not show the starch reaction. No starch was formed in the part shut out from the light.

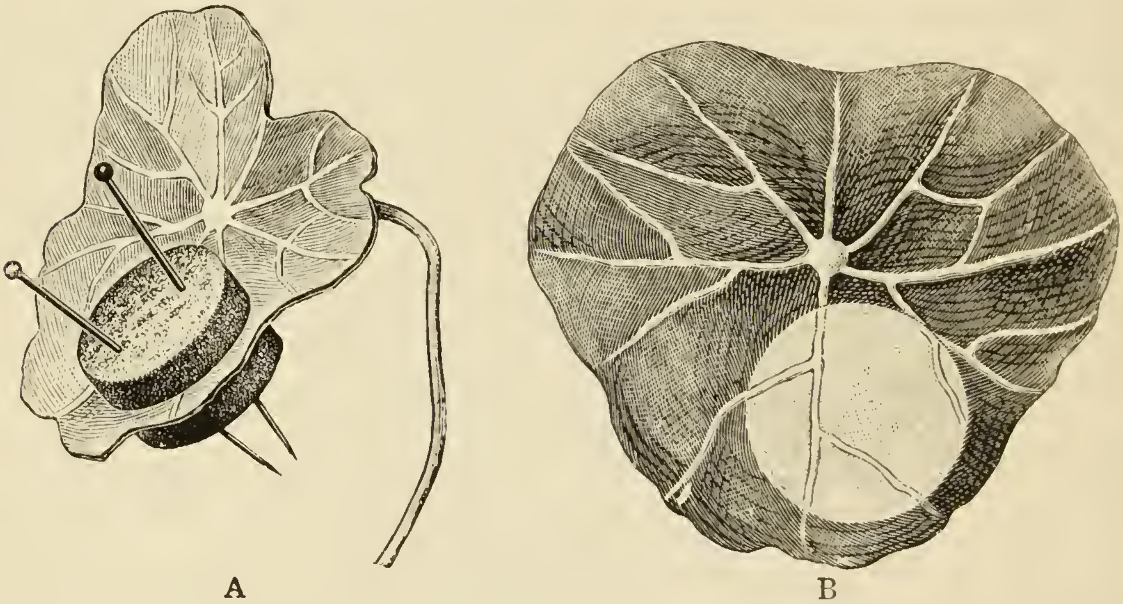

FIG. 87.—Nasturtium leaf. On the left, A, with a portion darkened; on the right, B, the same leaf treated with iodine and showing starch where exposed to light, but no starch where the leaf was shut out from the light.

Experiment.—Take a healthy leaf with a leaf-stalk cleanly cut, and after putting the leaf-stalk in water, place the blade into the mouth. Then blow air through the leaf, and it will escape from the cut leaf-stalk into the water. With a primrose leaf blow through the stalk, and thence through the leaf into the water. These experiments prove the existence of stomata in the leaves, and the connection of these with the air-spaces between the cells of the leaf and leaf-stalk (Fig. 84).

Experiment.—Another proof that the chloroplasts (par. 20), or granules of cell protoplasm, that contain chlorophyll, are the agents in a leaf of the construction of the visible carbohydrate called starch is furnished by taking a *variegated leaf*, that is, a leaf part of which is green and part of which is white. After being exposed to the light during the day, such a leaf, on being tested for starch, will show the dark blue colour only in the parts that were green, the white parts showing no blue.

55. Assimilation.—Assimilation is the process by which a living organism converts the absorbed food-substances into the substances composing it. In the plant, one part of this process is the formation of such carbohydrates as starch and sugar in the mode just described. Some of this starch and sugar may be stored as reserve food, but some of it is also united with the food-substances taken up by the roots, especially the nitrogen compounds so absorbed, in order to form the proteids that enter into the living substance called protoplasm. How and where the complex proteids of plant-substance are formed is a matter too difficult for the student at this stage of his studies (see par. 50).

The word *assimilation* is sometimes used by botanists for the fixation of carbon, and the formation of starch from it and the hydrogen of water. But it is better to use it in the wider sense above, as in animal physiology, and to use the term "carbon-fixation," or **photosynthesis** (Gk. *phōs*, *photos*, "light"), for the process dependent on light. As just shown, the green foliage leaves, or rather the particles in the leaves containing chlorophyll, are the agents of photosynthesis.

CHAPTER IX.

THE RESPIRATION OF PLANTS.

56. Respiration.—By **respiration**, or breathing, is meant the taking in of oxygen and the giving out of carbon dioxide by a living being. It was once thought that the difference between plants and animals could be expressed by saying that plants absorb carbon dioxide from the air and give back oxygen, while animals absorb oxygen and give back carbon dioxide. But though this statement is true, it is not a complete account of the relation of a plant to the gases of the air, for a living plant, like an animal, is respiring continually—that is, taking in oxygen and giving out carbon dioxide, although the process is much slower than in the higher animals. The oxygen taken in unites with organic matter in the tissues of the plant, and such oxidation of organic matter results in the formation of carbon dioxide and water as waste products. The process of taking in oxygen and giving off carbon dioxide goes on at all times and in all parts of the plant, while the process of taking in carbon dioxide to retain the carbon and set free an equal volume of oxygen only takes place during daylight in the green parts of plants. But as the amount of carbon dioxide taken in and of oxygen set free by plants is far larger than the oxygen absorbed and the carbon dioxide evolved, it is quite true to say that the total effect of plants upon air is to purify it for man and animals by assimilation of the carbon of the carbon dioxide and the setting free of the oxygen of this compound. Although going on in all living cells, the process of respiration in plants is best seen with germinating seeds or opening flower-buds.

57. Proofs of the Absorption of Oxygen and Elimination of Carbon Dioxide by Plants.—If we place a number of germinating seeds and a number of flower-buds into two bottles, and then close the bottles for a day, we shall find, on examination at the end of this time, that the air inside each bottle has undergone changes. On pouring clear lime-water into one bottle and shaking it up, the lime-water at once becomes milky. This indicates a large proportion of carbon dioxide in the air of the bottle, for the small quantity that is in ordinary air does not produce this effect. A taper placed in the other bottle is at once extinguished, as there is not enough free oxygen left to support its combustion. These results will follow whether the bottles have been kept in the dark or in the light. Hence we conclude that growing seeds or buds use up oxygen and give off carbonic acid. The other parts of plants can easily be proved to respire in the darkness in the same way as the germinating seeds, and general considerations about the activity of protoplasm or living matter convince us that they respire at all times (par. 2).

Experiment.—An instructive experiment on the respiration of germinating seeds, which shows that oxygen is used as they respire, can be carried out as follows: Take some peas that have been soaked in water and kept warm, so that germination has just begun. Put the germinating peas into a jar, together with a narrow beaker containing a strong solution of caustic potash—a substance which absorbs carbon dioxide. Cork the bottle with a rubber cork, through which a tube with coloured water is fitted, as in the figure. The coloured water will at first stand at the same level in the two arms of the bent tube, as the air-pressure in the two arms is equal. After some hours the water is seen to rise in the arm which is in connection with the air in the bottle, because the air in the bottle becomes less, as is shown by the diminished pressure inside. Now, we have just stated and learnt to prove by lime-water and a lighted taper that germinating seeds give off carbon dioxide, and we know that this carbon dioxide is absorbed by the caustic potash. But if the seeds merely gave out this gas, and it were taken up by the caustic potash, the volume of gas in the bottle would remain the same. The diminution of gas in the bottle must therefore be owing to the absorption of oxygen by the germinating seeds. Germinating seeds therefore absorb oxygen and give off CO_2. We know from other experiments that no nitrogen is taken from the air by such seeds.

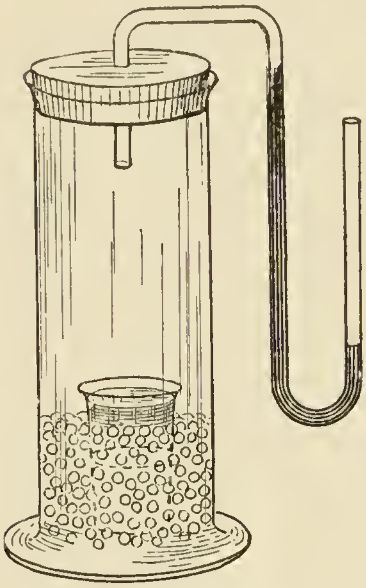

FIG: 88.—Experiment illustrating the respiration of germinating peas.

58. Respiration produces Heat.—We have learnt from many experiments that a process of oxidation is a process of combustion and accompanied by the production of heat, the heat being produced where the oxidation is going on. This occurs in all parts of our own bodies where the oxygen taken through our lungs and carried by the blood to all parts is being used up. Heat is likewise set free in plants, though the process of oxidation in them is much slower and less vigorous. A thermometer passed through a cork into a bottle of germinating seeds will show a little higher temperature—one or two degrees—than the surrounding air.

Experiment.—Another mode of showing that germinating seeds give off heat during germination is as follows: Place an empty flask, to which a bent tube is attached by means of a rubber cork, as in the figure, among a mass of germinating peas or barley-grains. In the two arms of the tube coloured water is placed, so that it stands at equal levels, l, l′, in each arm. The heat from the germinating seeds causes the air in the flask to expand, and this forces the column of air in the neare limb of the U part of the tube down, and it rises in the other part. There is much greater movement here than in the column of mercury in the thermometer, as air expands much more than mercury for the same amount of heating.

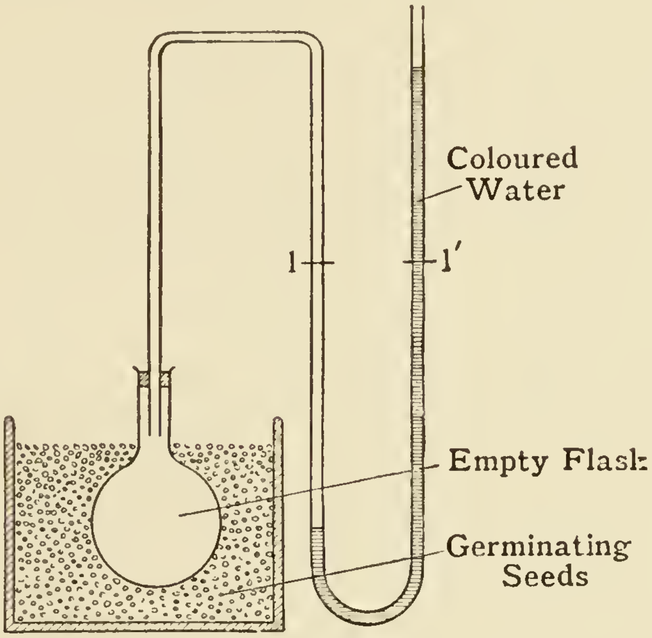

Fig. 89.—Experiment showing the production of heat by germinating and respiring seeds.

59. Comparison of the Processes of Respiration and Carbon Assimilation in Plants.—It will now be instructive to compare and contrast the two relations in which plants stand to the air, *i.e.* the processes of oxidation and reduction or respiration and carbon assimilation—two processes which must not be confused.

Respiration.	Carbon Fixation or Assimilation.
1. Oxygen is taken in.	1. Carbon dioxide is taken in.
2. Carbon dioxide is given off.	2. Oxygen is given out.
3. Respiration goes on in all the living parts of plants.	3. Carbon fixation and its results go on only in the green parts of plants, *i.e.* in the parts containing chlorophyll.

4. Respiration goes on at all times, and does not depend on light.	4. Carbon fixation only goes on in the daytime, as it depends on light.
5. Respiration is a process that is common to both plants and animals.	5. Carbon assimilation is a process occurring only in green plants.
6. The dry weight of the plant is *diminished* by the liberation of carbon dioxide that results from oxidation of plant matter.	6. The dry weight of the plant is *increased* by the fixation of carbon used in formation of carbohydrates.

As already remarked, respiration, or the taking in of oxygen and the giving out of carbonic acid, is much slower and less energetic in plants than animals. During the daytime the green plant takes thirty times as much carbon dioxide from the air as it gives off, and it gives back thirty times as much oxygen as it uses. At night respiration alone goes on, but so slowly that the popular idea of the unhealthy effect of living plants in a sleeping-room is much exaggerated. A single candle or gas flame burning in a bedroom will give off more carbon dioxide than a dozen plants.

CHAPTER X.

THE FERTILIZATION OF PLANTS.

60. Fertilization of Seed Plants.—As we have already learnt, flowering plants, like the wallflower, the cherry, and the bean, are capable, under certain conditions, of producing seeds. Flowering plants, therefore, are often spoken of as **seed plants.** We know further that from a seed a plant like the parent is produced when the seed is allowed to germinate and to continue its growth. On the other hand, a plant like the fern produces no flowers and no true seeds, but only spores (par. 36); and with these plants we are not at present concerned. Seeds are produced from the ovules found in the ovaries of the pistil of a flowering plant, but experiments have clearly proved that fruitful seeds cannot be produced unless the pistil receives a supply of pollen; and ovules are not able to produce seeds without pollen, while pollen-grains alone are useless for this purpose. The pollen may then exert such an influence, called **fertilization,** on an ovule that in time a seed results. As before explained (par. 17), a seed results from the union or fusion of two parts—a male reproductive cell contained in a pollen-grain from a stamen, and a female reproductive cell called the egg-cell in the interior of an ovule. When a pollen-grain falls on a ripe stigma it sends down a tube through the style until it enters the micropoyle of an ovule. Along this tube a generative cell from the pollen-grain travels, and entering the ovule meets the egg-cell, with which it fuses (Fig. 27). This union is the act of fertilization, and causes the ovule to ripen into a seed. Unless the ovule is thus fertilized by the cell from the pollen-grain, it withers and dies. The whole process by which the pollen reaches the stigma and then acts upon the ovules so as to produce seeds, may be called **fertilization**; but the first stage of this process, the transference of the pollen to the stigma, is also known as **pollination.**

Since the pistil of a flower must receive pollen before its ovules can be fertilized, it is important to notice the different modes in which the transference of pollen to a stigma may be effected.

When a stigma receives pollen from the stamens of the same flower, **self-pollination** is said to take place. When a stigma of one flower receives pollen from the stamens of a flower on a different plant of the same kind, **cross-pollination** is said to occur. There is another kind of cross-pollination, where pollen from one flower is transferred to another flower on the same plant. Where self-pollination is followed by fertilization, the plant is said to be **self-fertilized**; and where cross-pollination is followed by fertilization, the plant is said to be **cross-fertilized.**

The provisions developed by flowers for obtaining pollen for fertilization are very various. In some perfect flowers that have both stamens and pistils, the anthers of the stamens are higher than the stigmas of the pistils, so that when the anthers open the pollen simply falls on a stigma. In other cases, like the fuchsia, where the style is longer than the stamen, the flower hangs down and the stigma may thus receive pollen again as it falls. But self-pollination and self-fertilization are not so common as cross-pollination with cross-fertilization, and it has been found that better seeds, *i.e.* seeds better in quality and productive power, are produced as the result of cross-fertilization.

61. Obstacles to Self-fertilization.—In order to hinder self-fertilization, and to secure cross-fertilization, and by it better seeds, various arrangements or devices are found among flowering plants.

(*a*) Sometimes the stamens and pistils of a flowering plant ripen at different times, so that when the stigma is ready to receive pollen, the anthers of the stamens have either already given up their pollen, as in the meadow Geranium, or they are still unripe, as in the common Arums.

(*b*) In some cases the flower has its stigma above the stamens, or in other cases styles and stamens are of different lengths in the same kind of plant. Where the style is longer than the stamen and the flower is upright, the pollen in falling is not likely to reach the stigma. A primrose is a good example of a flower that occurs in two forms, one that has short stamens and another that has long stamens (Fig. 95).

(*c*) In some plants, as for example in many orchids, the pollen of the flower appears to have no power to fertilize the ovule of the same flower.

(*d*) In the case of some plants the stamens and pistils are produced on different flowers of the same plant, and are thus separated in space. This is the case with the hazel and the pine. In the hazel the long staminate flowers are **catkins**, familiarly spoken of as "lambs' tails." The pistillate flowers are at some distance and look like leaf-buds, but are distinguished from leaf-buds by the bundle of stigmas at the top (Fig. 91).

(*e*) Some plants, like the willow, produce only stamen-bearing flowers on one tree and pistil-bearing flowers on another (Fig. 90). The bright yellow staminate flowers of the willow are visible as catkins in the early spring, while the more sober gray pistillate catkins may be found on another tree. The pollen from the staminate flowers is carried to the pistillate flowers of another tree mostly by insects.

62. How Cross-fertilization is effected.—Cross-pollination leading to cross-fertilization is brought about by the transference of the pollen of one flower to the stigma of another in two chief ways: (*a*) by the wind; (*b*) by insects or other animals. In a few cases pollen-grains are carried by water.

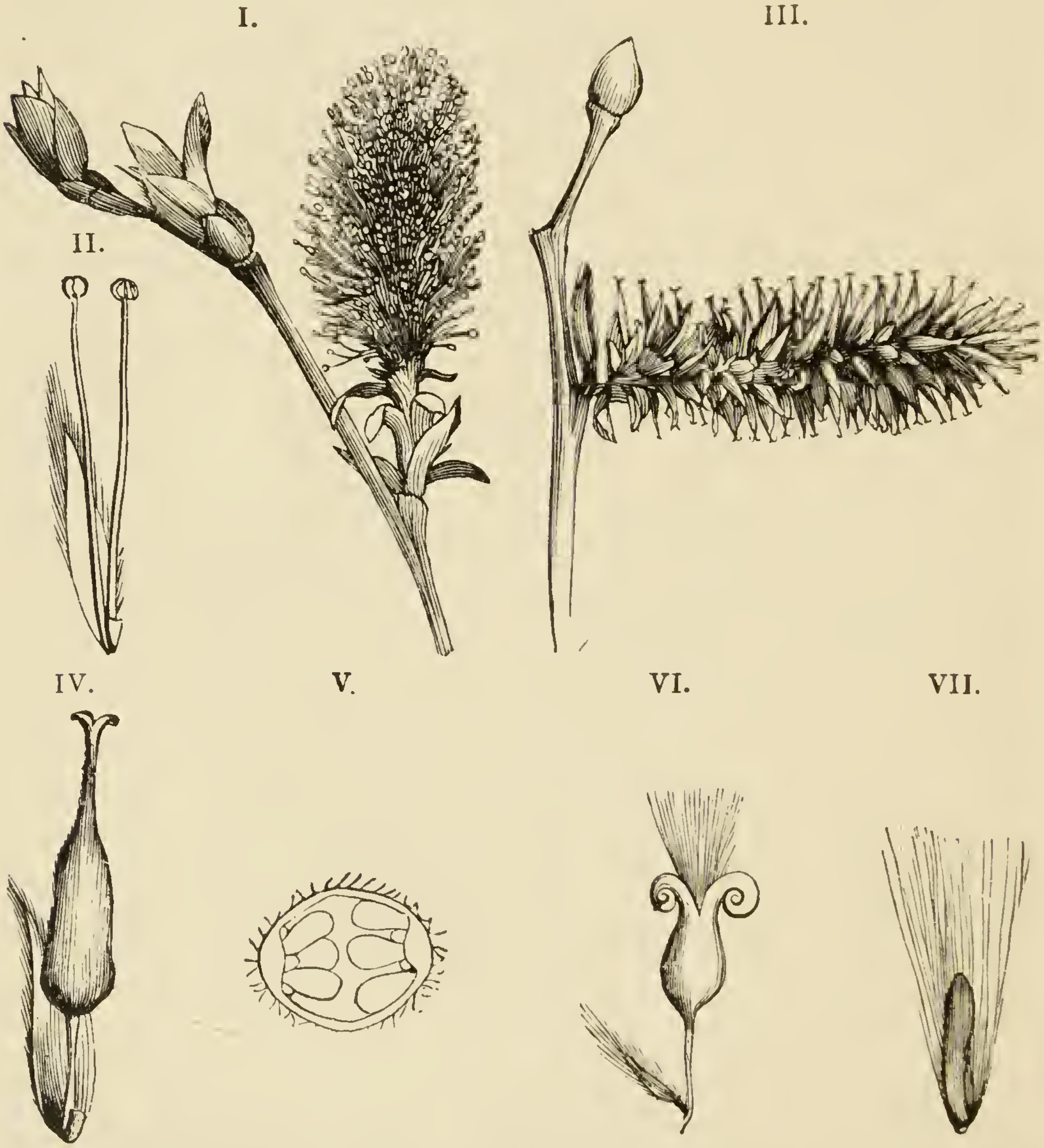

FIG. 90.—Willow (*Salix caprea*). I. Male catkin (natural size); II. male flower (magnified); III. female catkin (natural size); IV. female flower (magnified); V. transverse section of ovary; VI. fruit; VII. ripe seed (magnified).

(*a*) The wind is the agent which carries the pollen of one flower to the pistil of another flower in the case of many plants. In this case the flowers are usually quiet in colour and produce large quantities of dry pollen, which, when the anthers burst, is carried away often in showers by the wind. Some of it then alights on the stigmas of other flowers, and these flowers may be on the same plant or on plants at considerable distances. The pines, poplars, hazels, oaks, beeches, birches, and the grasses are wind-fertilized plants. In none of these cases is there a conspicuous calyx or corolla.

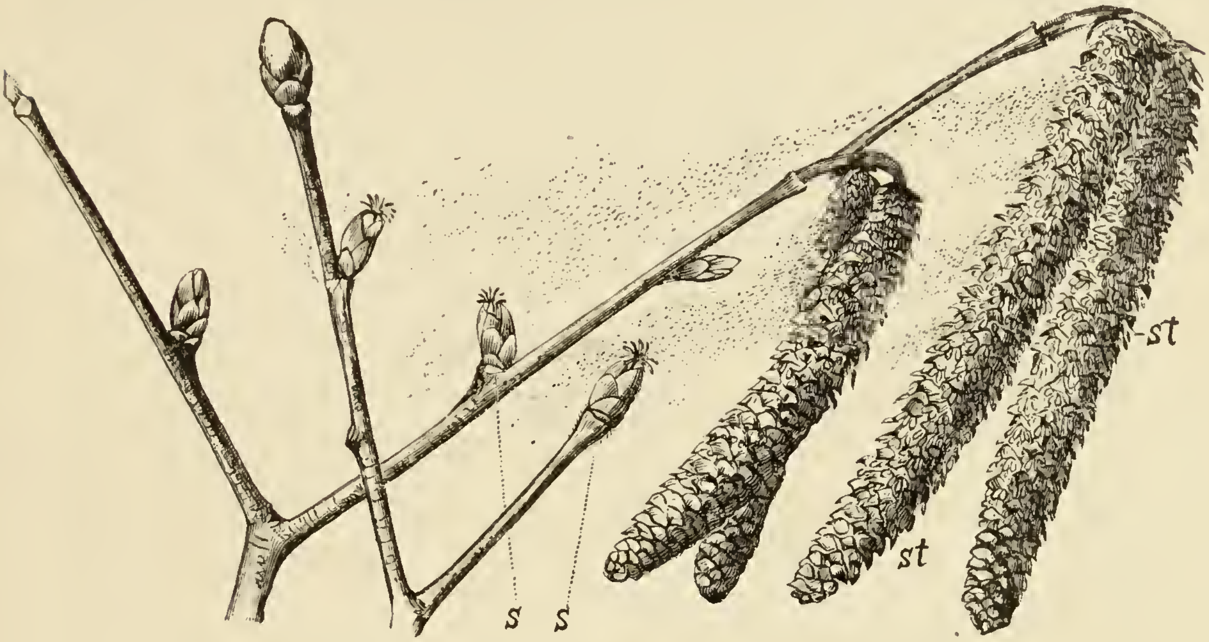

FIG. 91.—Branch of hazel, with male staminate catkins, *st*, from which pollen is being carried by the wind to the stigmas of the pistillate flowers, *s*, *s* (natural size). (Wellstein.)

(*b*) Certain animals, chiefly insects, as bees, butterflies, moths, and flies, act as carriers of pollen for many plants. Such insect-fertilized flowers have mostly bright-coloured petals, perfumes, or stores of nectar that serve as attractions.

The organs of plants that produce honey or nectar are called **nectaries**, or honey-glands, and they are situated in different positions in different plants. In the buttercup a small nectary occurs at the base of each petal ; in the wallflower the honey-glands, or nectaries, are just inside the bases of the two shorter stamens (Fig. 20) ; and in the bean flower and the flower of the pea the nectar is secreted at the bottom of the tube formed by the united filaments of the stamen (Fig. 59). The position of the nectaries is always such that the insect that can get the honey must knock against the anthers, and thus get pollen on some part of its body. Only certain insects can get the honey from certain flowers. When the honey, for example, is at the bottom of a long tube, only bees and other insects with long sucking organs can reach it. In such flowers as the buttercup, where the honey is easily reached, small flies as well as larger insects visit it, both for the honey and for the pollen, for bees and other insects use both pollen and honey as food.

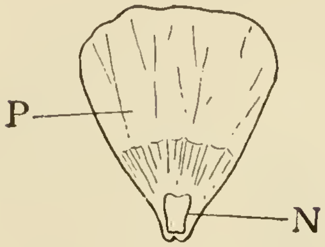

FIG. 92.—Meadow buttercup (*Ranunculus acris*). P, petal; N, nectary. (From Farmer's "Practical Introduction to the Study of Botany.")

In the tropics large bell-shaped flowers are often fertilized by humming-birds, whose long bills and tubular tongues enable them to obtain the nectar stored in these flowers, and in so doing carry away on their beaks or heads pollen-grains.

To understand how such insects as bees and butterflies obtain the honey of flowers, and in so doing act unintentionally as carriers of pollen and agents of cross-fertilization, we must remember that most of them are provided with a sucking organ, or proboscis, which enables them to get the honey from deep-seated nectaries, and that their legs, heads, and other parts of the body are provided with hairs to which pollen-grains may become attached. As will be seen from the figure, the length of the suctorial mouth or proboscis varies greatly in different classes of insects, and it will be readily seen that where the honey is deep-seated in a flower, only those insects with a long proboscis can reach it. Indeed, the correspondence between the structure of a flower and its insect visitor is a most interesting subject. As Sir J. D. Hooker says, "The adjustment of the parts of the flower to the form and habits of the insect or bird, and of these to the flower, is so accurate, that it is vain to speculate whether the plant is best adapted to feed the animal, or the animal to fertilize the plant." Among insect-pollinated flowers are the following: buttercup, poppy, pansy, primrose, sunflower, foxglove, bean, pea, clover, apple, pear, cherry, horse-chestnut, etc.

A few examples of the mode in which a flower is fertilized by insect visits must suffice.

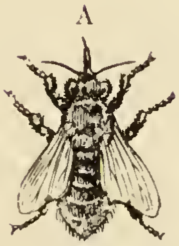

FIG. 93. – Bee. A, sucking organ.

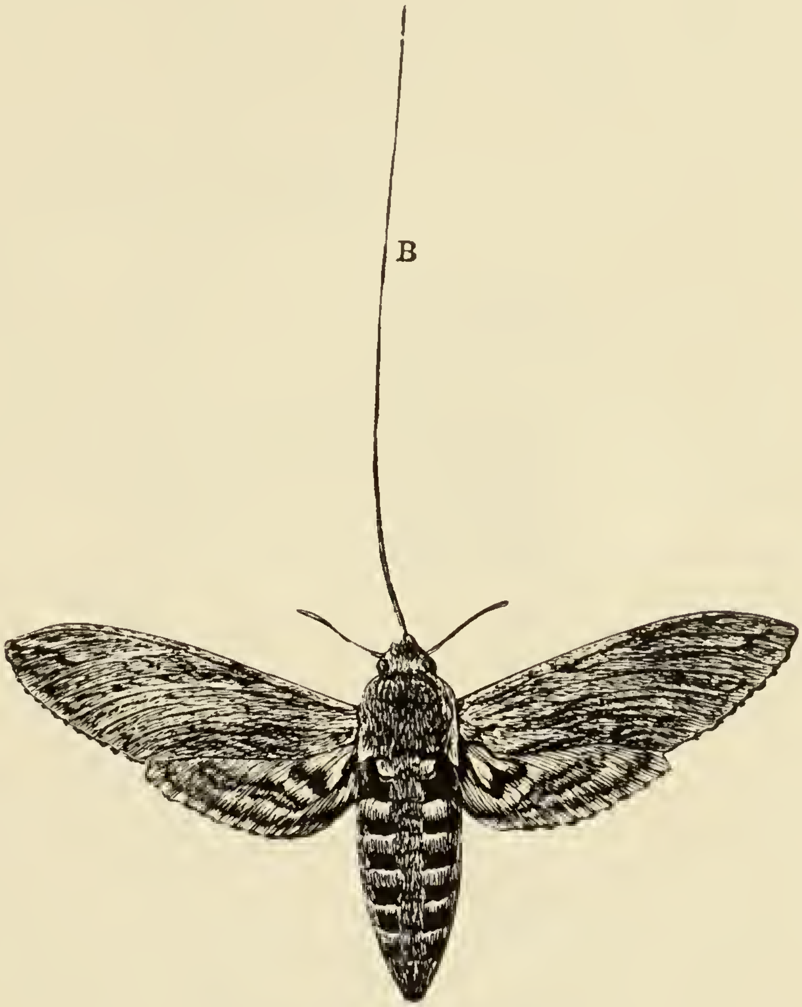

FIG. 94.—Convolvulus hawk-moth. B, sucking organ.

63. Examples of Cross-fertilization. — In such flowers as the *buttercup*, where the nectar is easily reached (in the buttercup it is at the base of each petal), many kinds of insects can obtain it, and in doing so become dusted with pollen. Small flies creep over them and carry away pollen, though they may also merely self-pollinate the flower. But where the nectar is secreted at the end of a long tube formed by a corolla or calyx, an insect like a bee or moth must effect cross-pollination.

In the *primrose* and *cowslip* we find two types of flower borne on different plants. One kind has long stamens with the anthers at the throat of the corolla-tube, and a pistil with a short style below the stamens. The other kind has a pistil with a long style and short stamens, so that the anthers are below the stigma, and as the flower is upright no pollen can fall on the stigma. A bee visiting a primrose with the long stamens gets his head and proboscis covered with pollen while sucking honey at the bottom of the tube. When it flies to a primrose with short stamens and a long style, he must transfer some of this pollen to the stigma of the long style. The long-styled primrose is thus fertilized with pollen from the short-styled one. The primrose with short style may be self-fertilized, but it can also be fertilized by a bee that has visited a long-styled flower; and it is found that seed so produced is more productive than when it is self-fertilized.

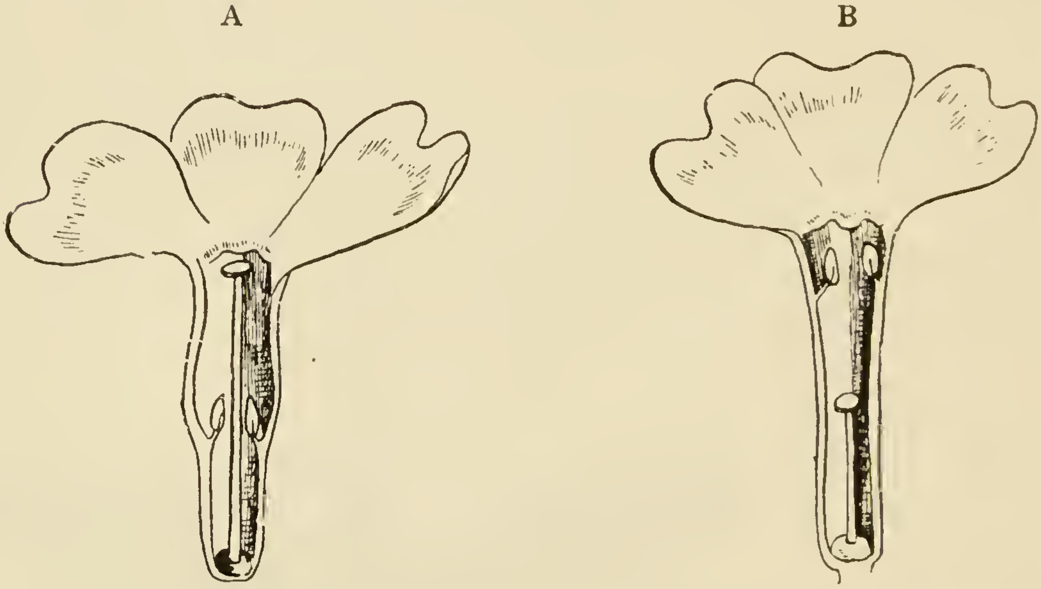

FIG. 95.—A, long-styled primrose; B, the short-styled primrose. (From Aitken's "Elementary Text-book of Botany.")

The *meadow sage* is a blue flower that has a large two-lipped corolla. The upper lip is arched, and the two stamens lie back within it. So also does the long thin style, with its cleft stigma, until the flower is ready for fertilization. The lower lip forms a convenient landing-place for bees and other insects.

To understand how a bee carries pollen from one flower to another, and thus aids in fertilization, it must be noted that the stamens are different from any that we have yet noticed. The two anther-lobes of each stamen are separated by a wide connective, so that the upper lobe of the anther is near the top of the upper lip; and the lower one, which

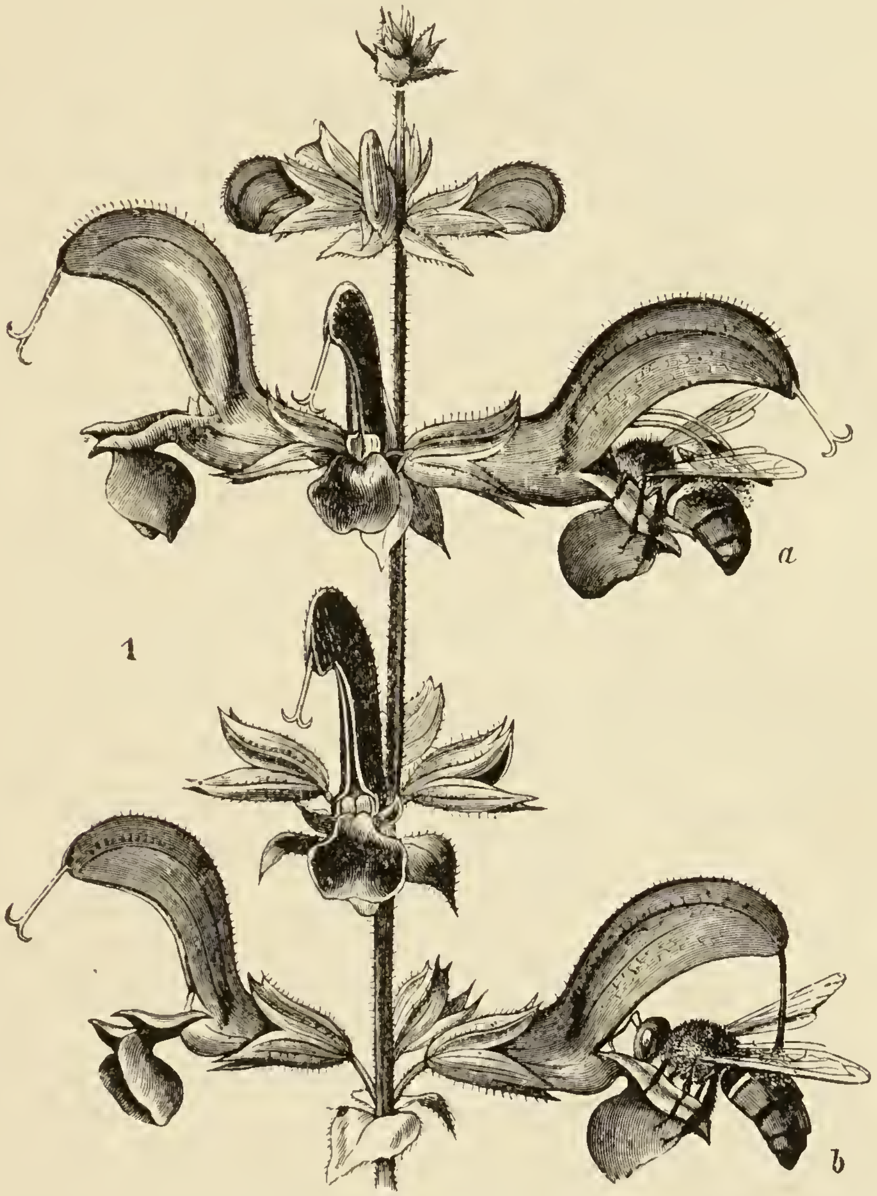

FIG. 96.—Flower cluster of the Meadow Sage. *a*, a flower with the cleft stigma and the style still in the upper lip; *b*, an older flower with the stigma bent down (see also Fig. 97). In the flower *a* the bee is receiving pollen on its back; in the flower *b* it is applying pollen to the stigma of a pistil.

is modified and barren, lies at the entrance to the corolla lower tube (see Fig. 97, where *st* is the connective, and *a* the expanded barren anther-lobe). A short filament passes from a point near the lower end of the connective by the lower lip of the corolla (from the point *d* in Fig. 97). Pressure against the lower anther-lobe causes the connective to turn about the point of attachment of the filament as on a pivot (see the figure, where an arrow is pressing at *a*), and to bring the upper anther with its pollen lower down. When a bee alights on the lower lip of the sage and pushes its head into the corolla-tube in order to reach the honey at the bottom of this tube with its proboscis, it causes the anther-lobe above to come down on its back, which thus receives a supply of pollen (Fig. 97). When the same bee enters another sage flower somewhat older, where the stigma is hanging down as shown at *b* (Fig. 96), this stigma receives pollen from its back, and thus becomes cross-fertilized.

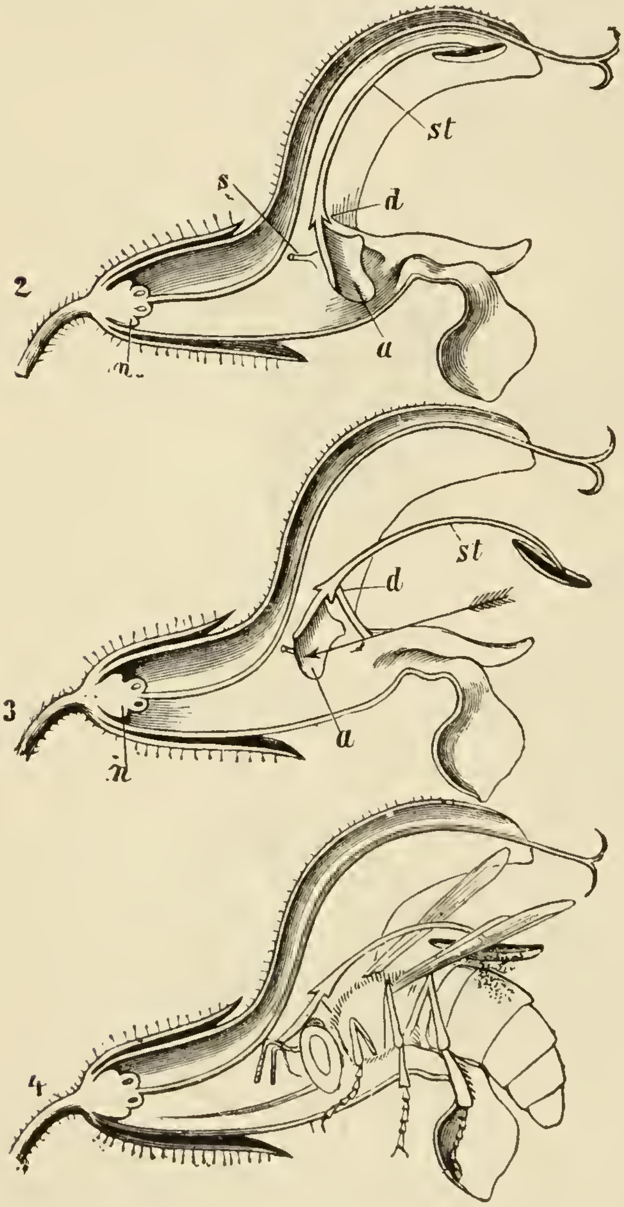

Fig. 97.—Sections of flowers of meadow sage, to illustrate structure and mode in which pollen is transferred by a bee. A push at *a* (as indicated by the arrow) causes the long connective *st* to turn about the point *d*, and bring down the anther on the back of the bee.

The flowers of the *bean* and *pea* are also well adapted for fertilization by bees. In these flowers the anthers of the stamens dehisce and shed their pollen just before the flower opens, so that it falls into the keel and upon the brush of the style, but not on the stigma (see Fig. 56). When a bee alights on one of these flowers, it settles upon the alæ or wings, and these petals being interlocked with the keel, both wings and keel are depressed. While the insect is thus resting on the wings, and probing with its proboscis for the honey secreted at the base of the staminal tube through the slit left by the tenth free stamen, the depression of the keel causes the anthers and the stigma of the style to emerge and touch the under surface of the bee's body. Some of the shed pollen is also sent up against the same surface. In this way the insect gets the hairy under-surface of its body smeared with pollen, and when it visits the next flower some of this is spread on the stigma, and that flower becomes cross-fertilized. On leaving the flower, after having sucked its nectar, the wings and keel rise up and again enclose the stamens and pistil, acting as before as a shelter from the rain for these parts.

Many other flowers are adapted to the visits of suitable insects, the visiting insect in search of nectar or pollen as food, receiving pollen on some part of its body which will come in contact with the stigma of the flower next visited.

Some flowers also show adaptation for warding off the visits of unsuitable insects, "unbidden guests," as these have been called. Thus the common snap-dragon has two lips so firmly closed that they can only be forced apart by a heavy insect as the bumble bee. In other cases a barrier of hair on the stem or in the flower often acts as a protection from small ants that might feed on the nectar, but could not act as suitable pollen carriers.

CHAPTER XI.

FRUITS AND SEEDS, WITH THE MODES OF DISPERSAL.

64. Fruits.—Every flower after fertilization forms a fruit. A fruit is a ripened ovary, though in many cases other parts of the flower—usually the receptacle—take part in its formation or are retained on it. When the flower consists either of one carpel or of united carpels, it forms a single fruit, as in the bean, pea, wallflower, cherry; but when the flower has several carpels that do not unite, one flower then forms several *simple* fruits, and the product of each flower is a compound fruit, as in the buttercup, blackberry, strawberry, and rose.

A fruit or ripened ovary consists of a covering, or **pericarp**, containing one or more seeds. The seeds are the ripened ovules. The pericarp of a fruit is formed from the walls of the ovary, and may be usually divided into two or three layers—an outer one called the **epicarp**, an inner one called the **endocarp**, and a middle one called the **mesocarp.** Taking the plum or cherry as an example, the skin is the epicarp, the pulp the mesocarp, and the stony shell the endocarp, of the fruit. The kernel is the seed.

Botanists divide fruits into two classes, according as they open when ripe to let out the seeds, or do not open. Fruits that open to let out the seeds when ripe are called **dehiscent fruits**; and those that do not open, **indehiscent fruits.**

A bean, pea, wallflower, poppy, etc., are dehiscent fruits. A bean or pea is formed of a single carpel and the pericarp, which may be separated into the three parts mentioned, splits down the front and back when ripe, and the seeds escape (Fig. 61). A wallflower fruit consists of two carpels united so as to form a kind of two-celled pod called *siliqua*, and when ripe it opens from below upwards (Fig. 24).

As examples of indehiscent fruits we may mention the plum, buttercup, strawberry, gooseberry, apple, acorn, ash.

The plum has already been described. The fruit of the buttercup consists of several distinct ripened carpels that have become hard, and each of which contains one seed. A strawberry consists of a rounded pulpy mass, with a persistent calyx at the base. The rounded pulpy mass is the enlarged flower receptacle; and the small, hard, seed-like bodies scattered over its surface are really the ripe fruit-carpels, each of which encloses a seed. In a gooseberry the fruit consist of two fleshy carpels enclosing seeds in a pulp, the seeds being attached to the skin, which is the pericarp.

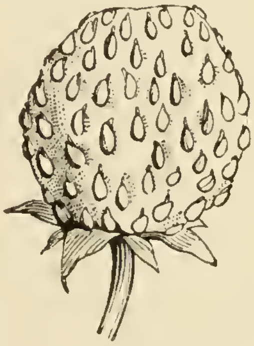

Fig. 98.—Compound fruit of strawberry, with small single fruits on a fleshy mass.

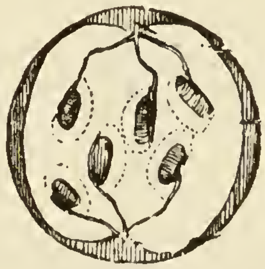

Fig. 99.—Transverse section through a gooseberry. The firmer outer layer of the pericarp encloses the succulent flesh; the seeds lie embedded in the latter, and are attached by long funiculi to two opposite parietal placentæ.

An apple is a fruit, the succulent portion of which is derived from the flower receptacle. A transverse section across the middle shows five membranous compartments, each of which is formed from an ovary, and each of which contains one or two seeds—the pips. The acorn is the fruit of the oak. Its tough outer covering is the pericarp, and the seed is the brown body inside.

The fruit of the ash is a winged fruit, or **samara.** It consists of two combined carpels enclosing a seed, and the pericarp is extended into a thin membrane that forms a winged margin. The elm has also a winged fruit. The fruit of the maple is a double-winged fruit, or double samara. Each pair of united carpels has a wing, and the double fruit separates when ripe, though the seeds do not fall out (Fig. 107). A dandelion or a thistle is not a single flower, but a head containing many distinct flowers. Each small ovary becomes a fruit containing a seed, and has a tuft of hairs called a **pappus** above; the pappus of the dandelion being at the head of a long stalk. When ripe the fruits are readily carried off by the wind.

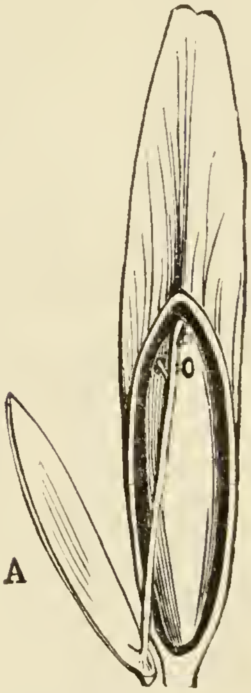

Fig. 100.—Fruit of the ash. The single seed attached to a long funicle, and still enclosed in the ovary; A, a detached piece of the pericarp.

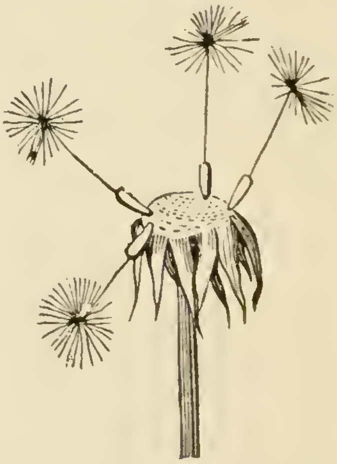

Fig. 101.—Four fruits of dandelion on receptacle.

65. The Seed.—A seed is a fertilized and ripened ovule, and should not be confused with a fruit. It is either sessile or attached to the pericarp of the fruit by a cord called the

funicle. The seed has its own coverings or coats, the outer covering being usually the stronger and the thicker, and known as the **testa.** Within the testa of the seed lies the embryo, or young plant. The embryo consists of the following parts: (*a*) a plumule, forming the apex of a rudimentary stem; (*b*) a radicle, or rudimentary root; and (*c*) one or more cotyledons (seed-leaves). These various parts have been examined in the bean seed, where we found two cotyledons. The pea, the white mustard seed, the sunflower seed, and the seed in the acorn, are other examples of seeds with two cotyledons. Plants arising from an embryo that has two cotyledons form a large division of the seed-bearing plants called **Dicotyledons.**

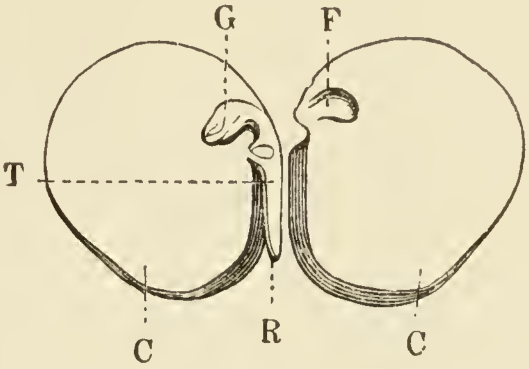

FIG. 102.—Pea split open, and seed-coat removed. R, end of radicle; T, axis of embryo; F, hollow in which plumule, G, lay; C, C, the two cotyledons.

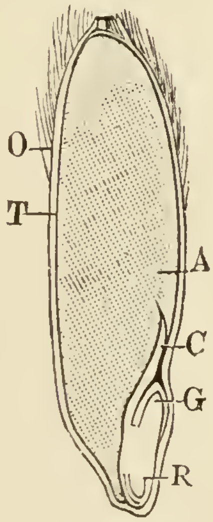

FIG. 103.—Longitudinal section of a seed of oat. A, endosperm; C, the single cotyledon, or scutellum; G, plumule; R, radicle; T, testa; O, hairs.

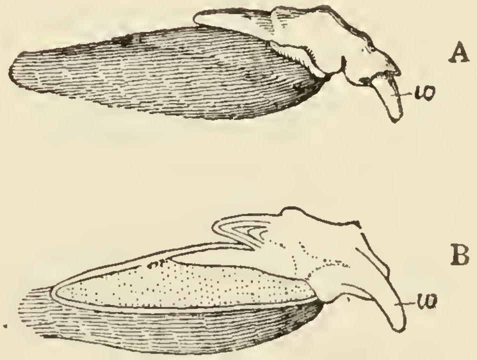

FIG. 104.—Oat-grains after soaking and stripping of the skin. A, outside view; B, sectional view. w = radicle, above which is the plumule. The scutellum, or cotyledon, adjoins the dotted endosperm.

There is another large division of the seed-bearing plants that has only one cotyledon, the **Monocotyledons.** If we examine an oat-grain or a wheat-grain, we shall find it differs from the bean or pea in several respects. In the first place, it is really a fruit, as the thin outer coat is the pericarp or wall of the ovary, and the real seed is within. But we may here speak of it as a seed. On softening an oat-grain, and making a vertical section through it, we may, if we use a lens, see that the embryo occupies one side of the base only, and that a great part of the seed does not form part of the embryo. The embryo consists of the same three parts as in the bean, but there is only one cotyledon (Fig. 103). The other mass of substance is called the "albumen," or more correctly the **endosperm**, and the seed is said to be *albuminous*. The wheat and the maize resemble the seed of the oat, having only one cotyledon and a large "endosperm." A pea or bean has no endosperm, and is said to be "*exalbuminous*." The endosperm serves as a store of food for the seedling, and is gradually absorbed by the young plant. The one cotyledon of the oat and maize is in the form of a plate lying against the endosperm, and is spoken of as the *scutellum*. When these seeds germinate the sheath enclosing the rootlets (the coleorhiza) is burst, as well as the covering of the seed itself.

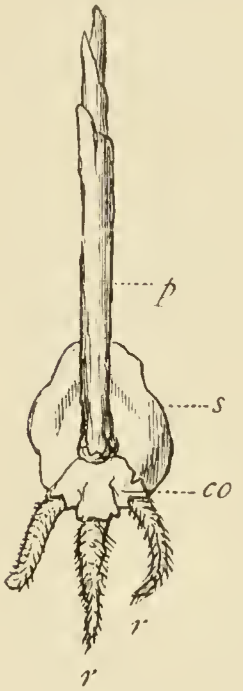

Fig. 105. — Germinating embryo of oat (the endosperm removed). *p*, the plumule; *s*, the scutellum; *r*, *r*, the rootlets; *co*, the coleorhiza, or root-covering. (From Edmonds' "Elementary Botany.")

66. Dispersal of Seeds.—It is to the advantage of a plant to have its seeds widely dispersed if new plants are to arise from them; for a seed has a better chance of surviving in the struggle for existence if it gets to unoccupied ground where there is little competition and a good supply of food and air. Nature has accordingly provided several means of transporting seeds to a distance from the parent plant, either after they have come out of the fruit or while they are still in it. In the case of fruits which open or dehisce, it is the seed itself that is scattered, but in the case of fruits which do not dehisce, the seed is borne away inside the fruit.

The means of seed-dispersal are: explosion of fruits, transportation of fruit or seed by wind, transportation by animals, and transportation by water.

(*a*) **Dispersal of Seeds by Explosion of the Fruit.**—Some fruits, owing to the drying of the pericarp, burst suddenly, and send out the seeds to some distance. This occurs to a small extent with the pea and bean, but it is more pronounced with the fruit of the furze, violet, herb Robert (a wild geranium), and garden balsam, in all of which the seeds are shot out of the fruit to some distance. The sand-box tree of the West Indies has woody capsules for its fruit that burst with a report like a pistol, and the seeds are then hurled with considerable force to a distance.

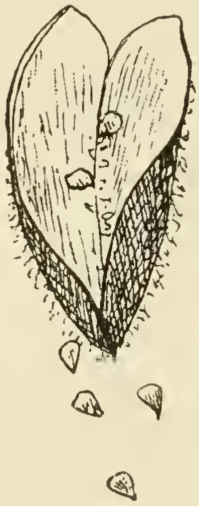

Fig. 106.—A furze-pod opening and shooting out its seeds.

(*b*) **Dispersal by Wind.**—Some fruits and seeds are very small, and are easily scattered by a breeze. In other cases, either the fruit or the seed is provided with a light, flat, wing-like expansion, which causes it to be readily blown through the air. This is the case with the fruit of the ash, elm, and maple, and the seed of the lime. The linden, or lime tree, has a wing-like leaf attached to its fruit. Another aid to dispersion by the wind is the possession of a hairy tuft, or plume. Thus the dandelion fruit has a long thin rod at the upper end, to which is attached a hairy plume, that makes it sail through the air with a kind of "parachute mechanism." The thistle fruit has also a hairy tuft at its top. So also have the seeds of the willow and the poplar. The small black seeds of the cotton plant are also provided with fine white hairs or fibres for dispersal. These fibres provide the cotton of commerce.

(*c*) **Dispersal of Seeds by Animals.**—Animals aid in the dispersal of seeds in several ways. In the first place, many fruits possess a rough, prickly covering, or have hooked appendages, so that such fruits cling to the fur, or wool, or feathers of animals, and are thus transported considerable distances before being rubbed or shaken off. The fruits with rough, hooked cases are known as "grappling fruits," or *burrs.* The common burdock has a fruit with hooked appendages. So also has the fruit of the forget-me-not and the woodruff.

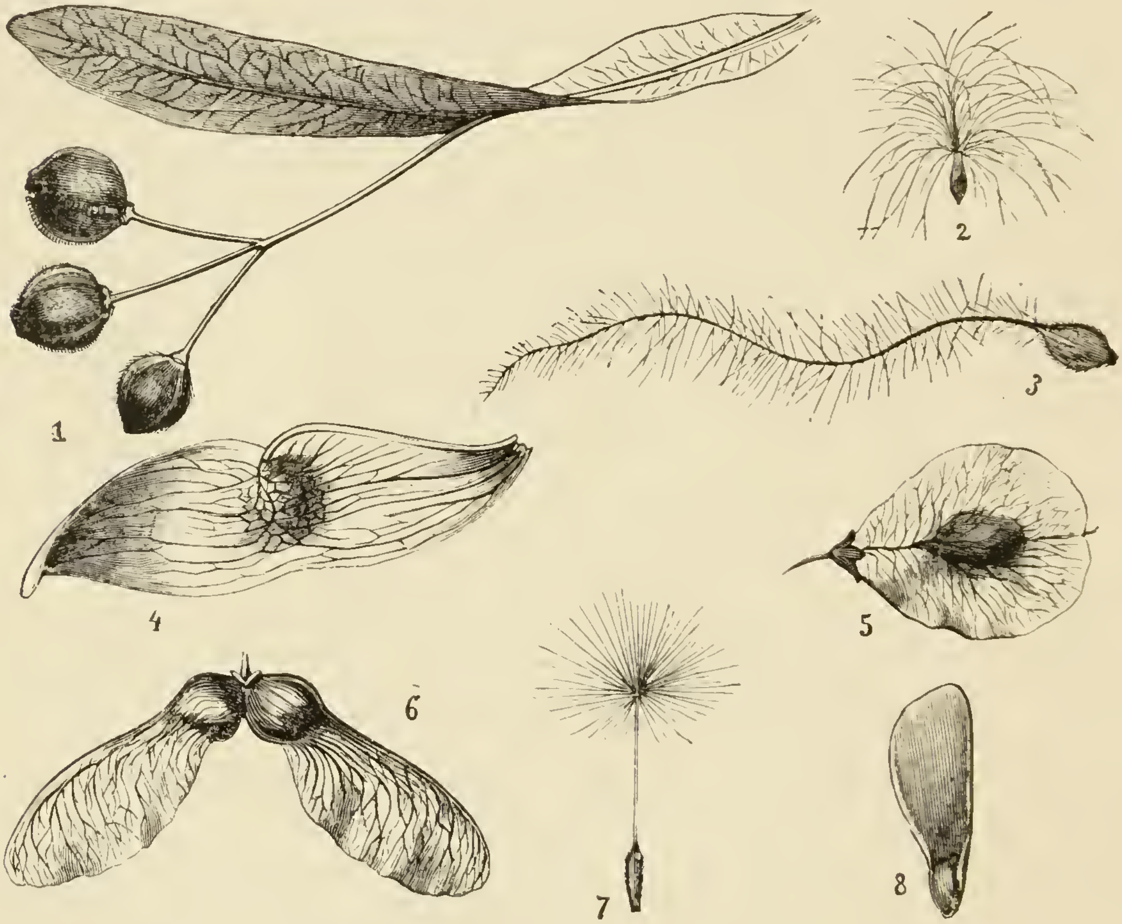

FIG. 107.—Arrangements on fruits and seeds for distribution by the wind (sailing fruits). 1, fruits of a lime tree with a wing leaf attached; 2, hairy seed of a willow; 3, fruit of clematis (lady's bower), with long hairy style; 4, fruit of the ailantus; 5, fruit of the elm; 6, fruit of the maple; 7, fruit of the dandelion; 8, winged seed of the pine. (Natural size. Wettstein.)

The bur-marigold has a fruit with two barbed appendages, and is sometimes called a "stick-tight." A walk through the woods in autumn will often leave a number of fruits fastened on the clothes by their grappling appendages.

Water-birds are great carriers of seeds on their feet and legs. The mud on the borders of ponds is usually full of seeds, and the wading-bird carries away a quantity of this mud clinging to its legs, and this mud does not drop away for some time, so that it may be at a great distance from the place where it was picked up.

Again, animals use fruits as food, and the seeds in many cases, being surrounded by a hard covering (as in haws and grapes, cherries, and strawberries), pass through the bodies without injury, and are discharged in a condition to germinate.

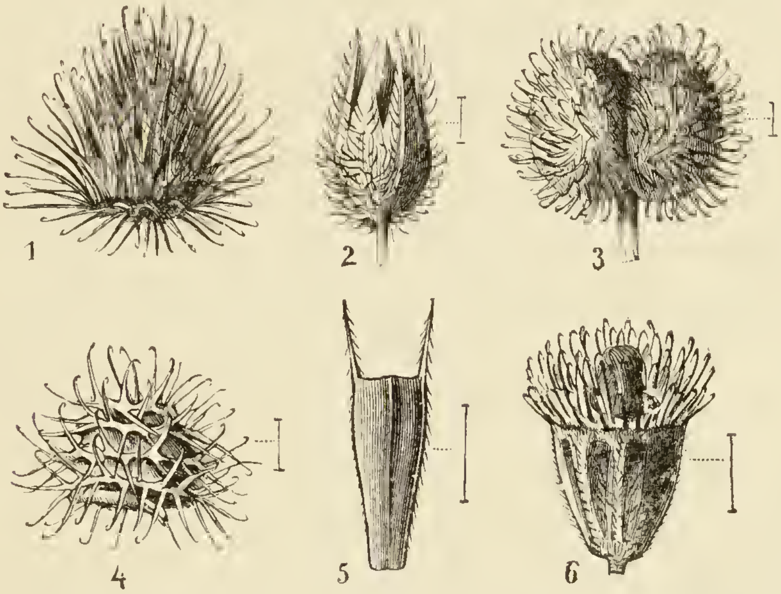

FIG. 108.—Arrangements on fruits for transportation by animals. 1, fruit-head of the burdock; 2, fruit-cup of the forget-me-not, with hooked hairs; 3, fruit of the woodruff; 4, fruit of the snail clover (*medicago*); 5, fruit of the bur-marigold; 6, fruit of the agrimony, with circlet of hooked bristles. (Fig. 1 natural size; the others enlarged as indicated. Wettstein.)

Further, in carrying off and eating pulpy fruits, birds often drop the seeds away from the parent tree.

(*d*) **Dispersal of Seeds by Water.**—The seeds of many water-plants and of plants growing by a river-side are often carried along for some distance, and afterwards left stranded. The seeds of the water-lily have air-spaces that keep them afloat a considerable time. Cocoa-nuts blown into the sea have been carried from one tropical island to another.

CHAPTER XII.

GERMINATION.

67. Germination.—Seeds vary greatly in size and shape, but all contain an embryo or young plant within the seed-coats. The relative size and arrangement of the different parts of the embryo also show considerable variation, the plumule in some cases being very small.

The embryo or rudimentary plant contained in a dry seed is not dead unless the seed has been kept too long.[1] It is only in a resting or dormant state. Three conditions are necessary in order to set its vital functions into activity. As already explained in speaking of the bean (par. 30), a seed supplied with moisture, warmth, and air (oxygen) awakes and begins to grow. Darkness is also an advantage for germinating seeds. This early growth is called germination. The embryo lives for a time on the food stored in the seed. This food is either stored in the cotyledons, as in the bean, pea, mustard seed, and acorn, or it is outside the cotyledons in the endosperm around the embryo, as in wheat, oats, maize, the pine, etc. When the store of food is round the embryo, it is called the **endosperm** (par. 65).

A germinating seed absorbs water, swells, and soon ruptures its seed-coat; first the radicle and then the plumule emerge. During this process it is respiring freely and giving off carbon dioxide (par. 57). By the time the store of food in the seed has been used germination is complete, and the seedling or young plant has both obtained a hold on the soil and reached into the air. From soil and air it afterwards gathers its food (par. 44).

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[1] The stories about mummy wheat germination after nearly two thousand years are mere fables. No such germination has been proved.

In the case of the broad or Windsor bean, the cotyledons, as we have seen, remain under the ground during germination, shrivelling up as their food-supply is used up (Fig. 47). The same occurs with the pea, the scarlet-runner bean, the acorn, and many other seeds.

In other cases the cotyledons rise above the ground, become green, and perform the assimilating functions like other leaves. Thus during the germination of the French or kidney bean the cotyledons escape from the seed-coats, rise into the air, and become green. These cotyledon leaves, though performing the function of leaves, are, however, different in form from the later foliage leaves which arise from the growing plumule above the cotyledons.

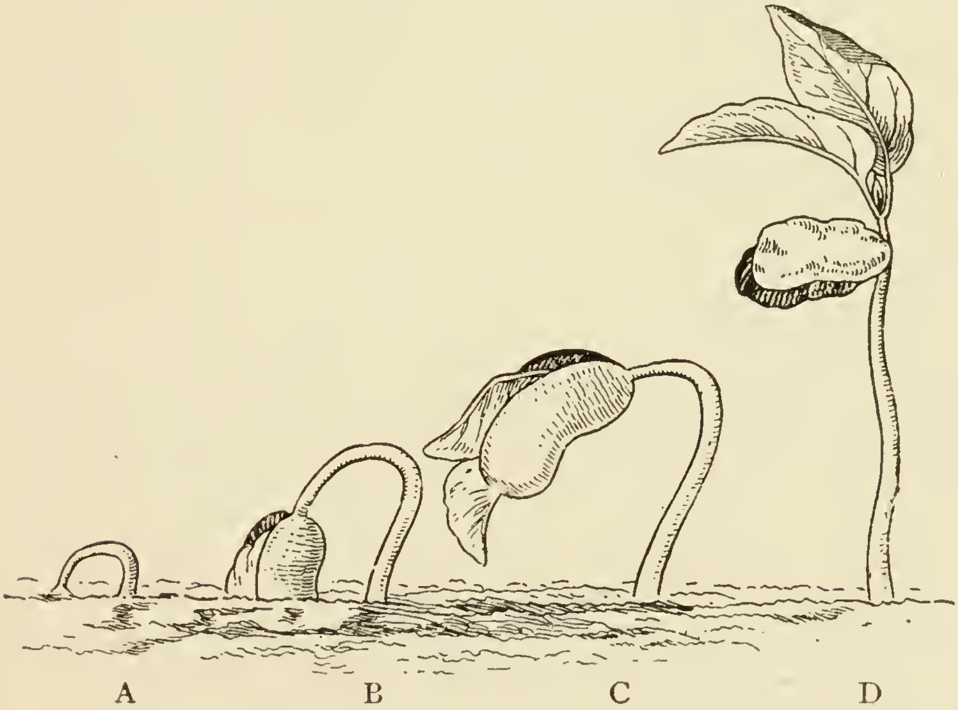


FIG. 109.—Germinating kidney bean. A, the hooked plumule above ground ; B, the plumule bringing the cotyledons out of the seed-coat ; C, the cotyledons above ground, and the first foliage leaves appearing ; D, the young stem upright, with the cotyledons and the first foliage leaves, with bud and growing point between.

Figs. 109 and 110 illustrate the earlier stages of the growth of the kidney bean. The reader should compare this with the broad or Windsor bean, where the cotyledons remain beneath the soil (par. 31).

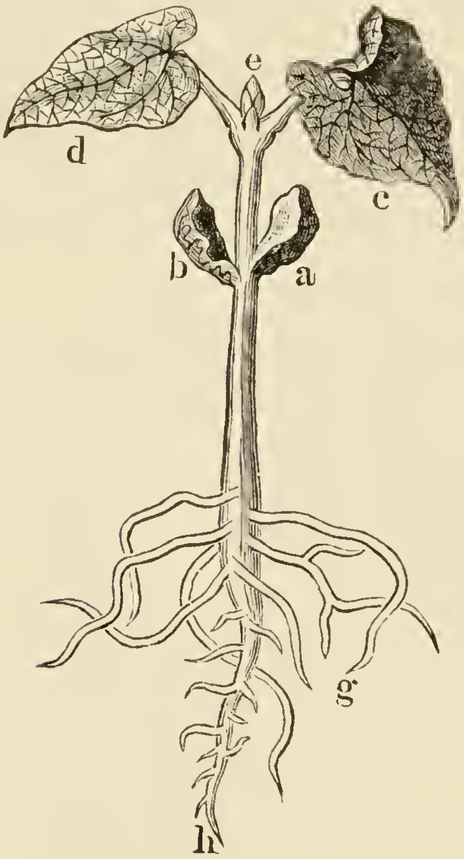


FIG. 110.—The seedling kidney bean further developed. h, primary root; g, lateral roots (root-hairs not shown); a, b, cotyledons; c, d, foliage leaves; e, terminal bud from which new leaves will arise.

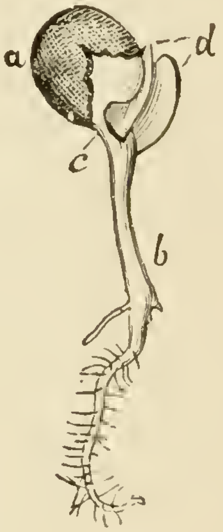


FIG. 111.—Germinating seed of cabbage. *b*, axis; *c*, *d*, the two cotyledons, which have risen above the soil, the testa *a* not being yet completely thrown off.

Experiment.—Place soaked seeds of cress, cabbage, or white mustard in damp moss or sawdust, and examine from time to time to note the process of germination. The cotyledons pass out of the soil as the hypocotyl (par. 29) lengthens, and the testa or seed-case is usually carried with them, to be afterwards cast off. Note how the plumule grows up between the cotyledons, and how the ordinary foliage leaves are unfolded.

Let us now consider the process of germination in a seed with one cotyledon. Wheat is a monocotyledon, as maize, oats, and barley. If a grain of wheat be soaked, it is easy to see through the covering the embryo at one end, on the side opposite the furrow. The other end has a slight hairy beard. On making a section lengthwise through the furrow, the embryo is seen to occupy but a small part of the grain, as the remainder is made up of a floury *endosperm*, as in the case of the oat (Fig. 103). With the help of a good lens, there may be made out the radicle of the embryo, the plumule, and a flattened shield-shaped structure called the **scutellum**, lying against the endosperm. This scutellum may be regarded as representing the single cotyledon, and it serves to absorb the nutriment from the endosperm for the growing embryo.

Experiment.—Place some wheat-grains in water, and after they become swollen put two or three upon damp sand, and others in damp sawdust or soil. In a day or two those resting on the damp sand will show the radicle breaking through the covering of the grain, and as the grain lies on its side, the radicle will be seen to turn downwards, as all radicles do (par. 30). Shortly after, two or three other similar roots come out from the lower end of the embryo alongside and above the chief root. There is no main tap-root giving off secondary roots as in the bean or pea.

Turning to those grains planted in the sawdust or soil, we find that soon there appears above the surface a pale leaf rolled up in the form of a tube. From an opening, as its tip, the first green leaf soon appears. Out of this another green leaf afterwards springs, and so on. If we pull up some of the more advanced seedlings, we find that the first root has ceased to

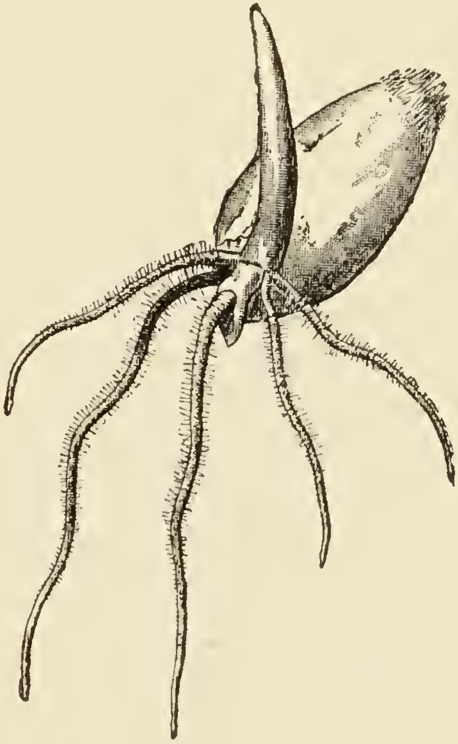


FIG. 112.—Wheat germinating. Rootlets have forced their way out through the coverings, and have developed hairs, and the plumule has also appeared.

lengthen, but that there is above and around it a bushy mass of roots all supplied with root-hairs. Note the clinging of the particles to the root-hairs. In the case of the grains planted in sawdust, these particles can readily be washed off.

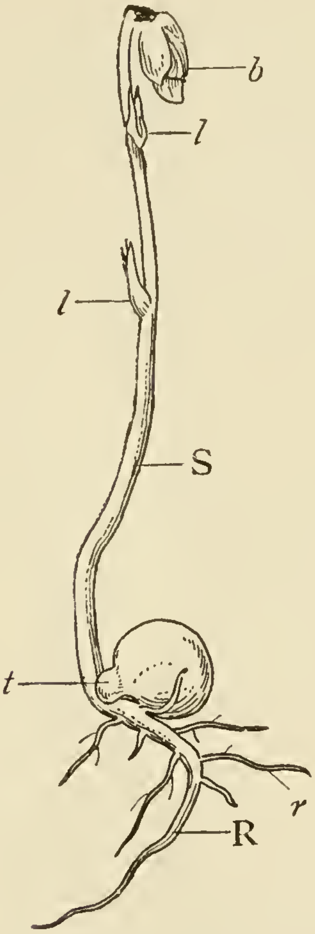


Fig. 113.—Garden pea. *b*, terminal (vegetative) bud; *l*, *l*, two first leaves after the cotyledons; R, primary root; *r*, lateral root; *t*, ruptured testa; S, young stem. (The cotyledons are enclosed within the testa.) (From Farmer's "Practical Introduction to the Study of Botany.")

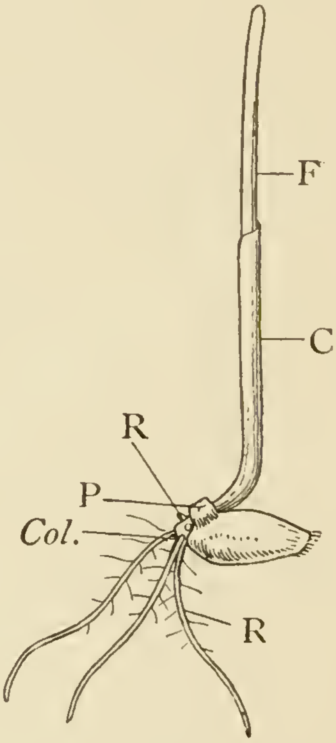


Fig. 114.—Germination of wheat. C, cotyledon; *Col.*, coleorrhiza, with hairs; F, leaf; R, root; P, ruptured wall of fruit. (From Farmer's "Practical Introduction to the Study of Botany.")

68.—Comparison between a pea (or Windsor bean) and a wheat-grain, and between the germination of each:—

PEA.	GRAIN OF WHEAT.
1. The pea is a seed, the pale skin of which is the testa, or seed-coat.	1. The grain of wheat is really a fruit containing one seed. The covering is the pericarp or fruit-wall, and to it the testa of the seed is fused.

2. The space within the covering is entirely filled by the embryo.	2. The space within the covering contains a small embryo and endosperm.
3. The embryo consists of (*a*) radicle, (*b*) plumule, and (*c*) two cotyledons.	3. The embryo consists of (*a*) radicle, (*b*) plumule, and (*c*) one cotyledon.
4. During germination—	4. During germination—
(*a*) The cotyledons remain in the ground, shrivelling up as they supply the food required by the seedling plant until it can obtain its supply from the soil and air.	(*a*) The wheat-grain remains in the ground, but the first pale leaf representing the single cotyledon comes above. The endosperm supplies the food material until it is used up.
(*b*) The main root continues to grow and give off lateral branches.	(*b*) The primary root soon ceases to grow, and a number of roots develop above and around it.
(*c*) The plumule comes up curved, and afterwards becomes erect.	(*c*) The plumule comes up straight.

The difference in the *venation* of the foliage leaves of these two representatives of the two great classes of plants (dicotyledons and monocotyledons) may also be noted (see par. 15, Fig. 15).

Compare in the same way the structure and mode of germination of the acorn and the maize. The acorn is the one-seeded fruit of the oak, the seed lying within the brown shell that forms the pericarp. Lying within its own testa, the seed will be found to consist of two large cotyledons united to a small peg-shaped body at the pointed end that forms the radicle and plumule.

It may be noted that the presence or absence of endosperm with an embryo is not a distinction of the two great classes of plants, as some dicotyledons have this store of nutritive albumen, while some monocotyledons are without it.

CHAPTER XIII.

PLANTS AND LIGHT.

69. Conditions of Plant-growth.—During growth a plant is building up, from the simple inorganic food-materials obtained from the soil and air, various complex organic bodies, such as *sugar*, *starch*, *protoplasm*, etc. There is also, in consequence of respiration or the taking in of oxygen, a slow breaking-down of protoplasm and the consequent giving off of carbon dioxide. The external conditions necessary to growth are: (1) a suitable supply of water; (2) appropriate food-materials; (3) the presence of the oxygen of the air; (4) a suitable temperature. A proper amount of **light** is also required for the healthy growth of all green plants.

The first three conditions of growth have been sufficiently explained and illustrated in Chap. V. As regards temperature, there is for each kind of plant and seed a minimum temperature, below which growth ceases. Above this, growth begins slowly, until a certain best or optimum temperature is reached, at which growth goes on most vigorously. Above this optimum temperature the rate of growth decreases. For most common plants of this country the best temperature is about 98° F. (37° C.), the temperature of the body.

We proceed now to consider the relations of a plant to light.

70. Influence of Light on Carbon Assimilation in Plants.—It has already been shown that sunlight, either direct or scattered by reflection, is needed in order that the green parts of plants may be able to decompose the carbon dioxide of the air and assimilate the carbon (par. 52). This is indeed the most important of all the influences that light exercises on plant-life.

White light, as is explained in the earlier course (" Elem. Physiog.," Part I.), consists of a mixture of rays differing in colour and refrangibility. The colours of the spectrum, as usually stated, are red, orange, yellow, green, blue, indigo, and violet. By putting plants under variously coloured shades, it has been shown that in a mixture of red, orange, and yellow light the decomposition of carbon dioxide, with its attendant results, goes on almost as well as in white light. These, then, must be the active rays in assimilation. With blue and violet rays only, assimilation is very small.

Experiments.—To show the effect of light of different colours on green plants, twigs of aquatic plants may be put in spring water (Fig. 85), and then placed in a box with blackened inner surfaces, and the open ends closed with sheets of ruby, yellow, and blue glass in turn. A bell-jar may also be used, with double walls, as in Fig. 115. If a saturated solution of potassium bichromate (a reddish-yellow solution) be placed in the outer cylinder, and the jar be then placed in sunlight, oxygen is given off almost as freely as when the beaker is uncovered. With a blue solution, on the other hand, little or no oxygen is given off.

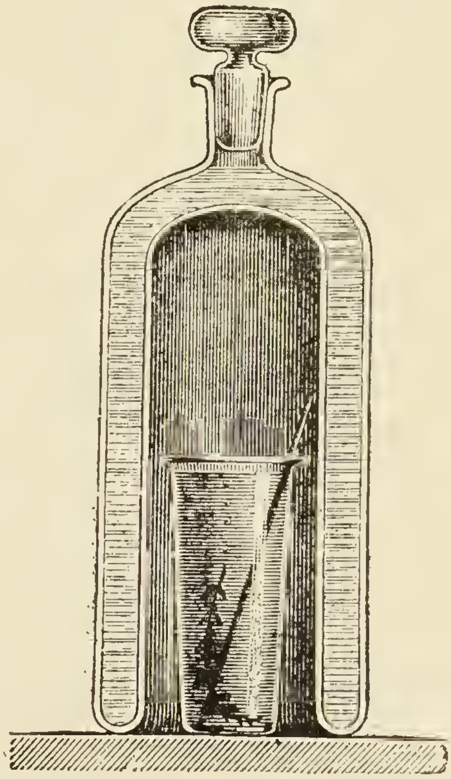


FIG. 115.—Bell-jar with double walls, for testing effect of coloured light on liberation of oxygen. (From Macdougal's "Elementary Plant Physiology.")

71. Plants grown in Darkness.—Sunlight is not essential to plant-growth of a certain kind, though a moderate amount is beneficial. If plants are grown in the dark, the stem will actually increase in length more quickly than in the light. It, however, not only becomes long, but it becomes slender and thin, while the leaves remain small and pale. No chlorophyll is formed in the absence of light, and no carbon assimilation goes on. "Forced rhubarb," as it is called, is grown in the dark, and has long slender stems with small pale leaves. Note also the pale grass beneath an overturned pail or a board that has been excluding the light from the plants beneath for several days.

Experiment.—Plant in pots, peas, cress, or mustard seeds, and grow some in the dark and others in the light, keeping the soil moist. After three or four weeks examine the plants, and note that those grown in the dark have long, weak stems, small, pale leaves, and that they are limp and drooping, if not dying. The plants grown in the light have shorter, stronger stems, larger green leaves, and appear healthy and vigorous. Hence, although a plant grows faster in the dark, light is required for healthy growth.

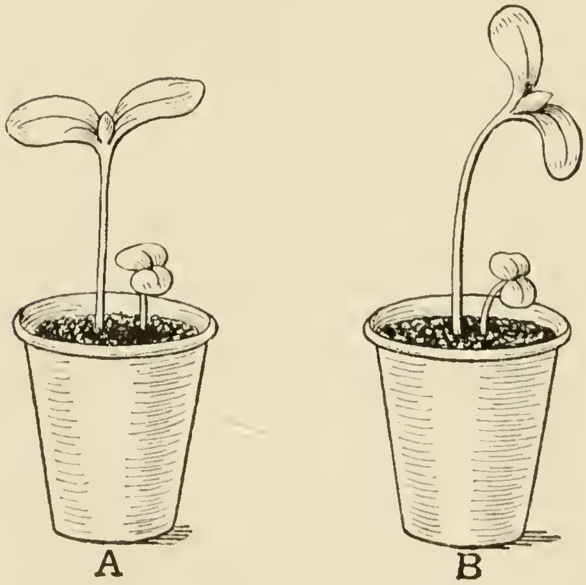


FIG. 116.—A, seedlings growing with the light from above; B, seedlings growing by a window with light from the right only.

72. Plants seek the Light.—Light influences the **direction** of growth of the stem and leaves. When there is light only on one side of a plant, the stem bends towards the light as it lengthens or grows faster on the shady side. The leaves also place their surfaces at right angles to the direction of the light rays as a rule.

This turning of the stem and leaves to the light can easily be shown by growing plants in a cellar, at a small distance from the window. A day or two will cause a change. Musk and nasturtium show the effect very well. Ordinary window plants like fuchsias and geraniums should be turned round occasionally to keep them straight and symmetrical. This turning of a plant towards the light is called **heliotropism** (Gk. *hēlios*, "the sun;" and *tropos*, "a turning")

The struggle for light, where it is not too abundant, may often be observed in plants growing under natural conditions. Where a tree is shaded on one side, the branches on the other side may be noticed stretching further out for light. Notice the more numerous and longer branches on one side of trees that grow on the rim of a forest—the side that is turned away from the other trees and open to the light. It may be noted here that roots and rhizomes turn away from the light.

73. Leaves seek the Light.—Not only does the plant as a whole as well as its branches seek the light, but leaves in particular generally thrive best where there is the best light, and they also arrange themselves, as a rule, so as to receive the greatest amount of light, the parts of the leaf, or its stalk, twisting to effect this. The outside of any large tree is much more densely covered with leaves than the inside. The leaves, too, are generally arranged so that each one obtains as much light as possible, and shades others as little as possible. At the top of an elm we shall find the leaves horizontal, with the length of the leaf-stalk so adjusted that the upper surface of each leaf gets

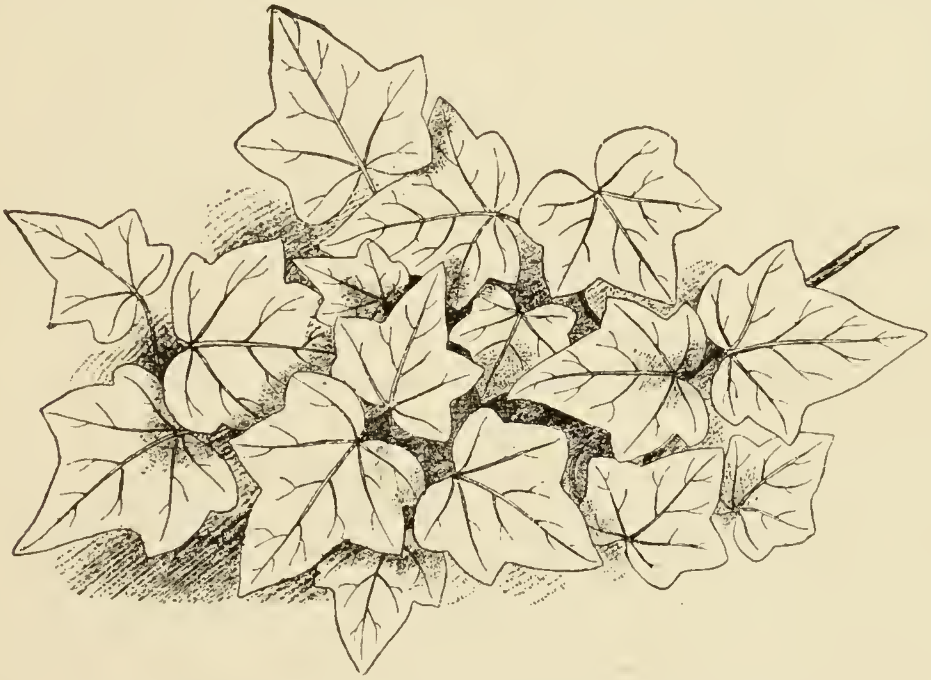


FIG. 117.—A mosaic of ivy leaves, showing how the position and form of the leaves are adapted to secure the light, and avoid shading.

its full share of light. The ivy, too, shows plainly, whether creeping on the ground or alongside a wall, how both the position and form of the leaf are adapted to the light exposure. The indented leaves are arranged so as to form a regular mosaic (Fig. 117).

The exposure of one particular surface to the light is due to the fact that that surface has the most chlorophyll in its cells, and that the work of light is therefore most effective on that surface. In some plants, however, the leaves are vertical, so that both surfaces are exposed. There are also some plants which avoid the light and thrive in the shade.

74. Day and Night Effects on Plants.—The account of the behaviour of plants with reference to light would not be complete without some notice of the changes that may be seen as night comes on and morning dawns. Movements are induced in the foliage leaves of many plants by alternations of light and darkness. Many leaves of the bean family of plants, as the scarlet-runner and meadow clover, have a day position during which the leaves are expanded, and a night position during which the leaves are folded together in a drooping position (Fig. 118). The movement originates, as a rule, not in the blade of the leaf, but in the swollen base of the leaf-stalk. Other plants that exhibit this day-and-night movement with their leaves are the wood-sorrel and the Dutch clover. The Mimosa, or sensitive plant, not only closes its leaves at night, but even in the daytime, if it be pinched. Movements of the kind just described, and effected in response to the varying light and temperature occurring during the change from day to night, are sometimes termed *sleep-movements*. The night position of the leaves of these plants doubtless serves to protect them from injury by cold.

Many *floral* leaves have also movements that lead to day and night positions. In most cases the flower is open during the day and closes as night comes on. Examples of this are the daisy and the dandelion. In a few cases, as with the evening primrose, the flower does not open until night. Such flowers as the last are fertilized by night-moths.

That light is the chief agent or stimulus which produces these alternating day and night movements is shown by the fact that the rising or falling takes place gradually as daylight or darkness comes on, and also by the fact that the falling takes place when the plant in the daytime is taken into a dark room, but disappears when the plant is again brought into the light.

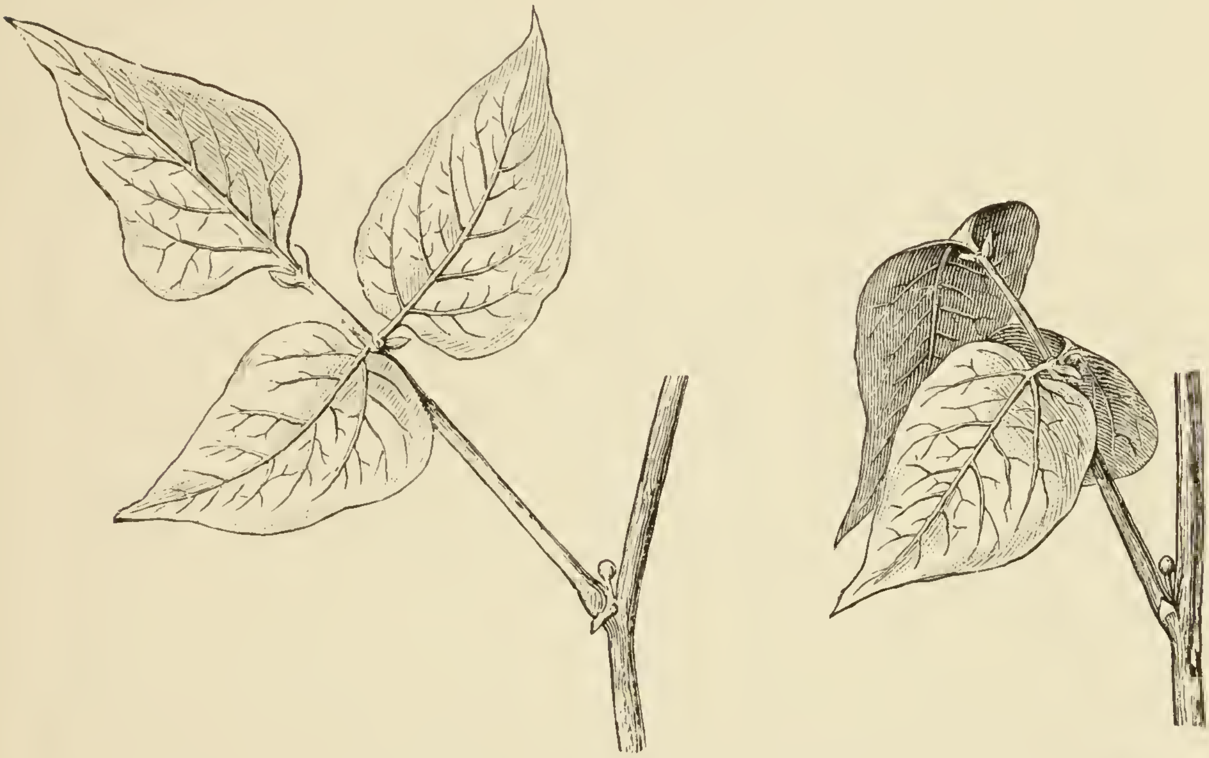


FIG. 118.—Day and night positions of the compound leaf of the scarlet-runner bean.

Experiments.—Examine the day and night positions of Dutch clover, and note how the three leaflets of a leaf fold so that one forms a roof over the other two, as in the runner bean (Fig. 118). Induce the sleep position by placing a clover plant in a dark room. Note the expanded horizontal position of the three leaflets of the wood-sorrel by day, and how the leaflets droop downwards at night, so as to look something like a closed umbrella. Pluck some well-opened daisies and dandelions on a bright day, and, after putting the stalks into water, place them in the dark. After an hour or so the flowers will be found closed, but on being removed into the sunshine they will open again.

CHAPTER XIV.

OUTLINE OF THE STRUCTURE OF THE HUMAN BODY, WITH DESCRIPTION OF ITS SKELETON.

75. General Build of the Body.—The bodies of all the higher vertebrate animals are formed on the same general plan, and consist of an internal bony framework and similar organs performing similar functions. Though there is this general similarity of structure, there are also certain differences adapting the structure of each class to its mode of life.

It is probably advisable for us to obtain a general idea of the build of the human body before we proceed to consider the structure of a quadruped as required by the syllabus of our course of study.

The human body may be divided into three principal parts—**head, trunk,** and **limbs.**

The **head** consists of an oval bony box called the **cranium** and the part called the **face.** Within the cranium lies the brain, while connected with the face are certain important organs of sense and the mouth. Connecting the head and the trunk is the round neck, the front of which contains the windpipe, or trachea, and behind this the food-pipe, or gullet. The skull rests on a jointed bony column called the backbone, or **vertebral column,** and this runs along the hinder part of the neck and the whole trunk. The **trunk,** which is the thickest part of the body, is divided into two compartments by a thin arched partition called the **diaphragm.** This diaphragm consists of muscle and tendon, and is attached all round at its edge to the walls of the trunk. Within the two compartments of the trunk lie the internal organs collectively termed the **viscera.** The upper compartment of the trunk above the diaphragm is termed the **thorax.** It is a kind of bony cage, being enclosed in front by the breast-bone, or **sternum**, behind by a part of the backbone, and on each side by the **ribs.** Within the thorax, in the middle, lies the **heart**, with the aorta and other great blood-vessels connected with it; and at the sides are the spongy masses of the **lungs**, with which is connected the trachea that passes from the back of the mouth down the front of the neck (see Fig. 119).

The lower half of the trunk below the diaphragm is known as the **abdomen**, or belly. The abdominal viscera include the **stomach, intestines, liver, pancreas, spleen, kidneys,** and **bladder**, most of these organs being surrounded and supported by a folding membrane called the **peritoneum.**

The **stomach** lies underneath the diaphragm on the left side. Leading into it above is the food-pipe or gullet, which has passed from the back of the mouth, and then behind the trachea and heart through the diaphragm. The stomach, which is a muscular and membranous bag, passes below into the coils of the small **intestines**, and these continue into the large intestine, which, after passing upwards, across, and downwards, terminates at the **rectum.** Gullet, stomach, and bowels or intestines, thus form a continuous tube termed the **alimentary canal.**

The **liver** is a large reddish organ lying on the right side under the abdomen. A smaller part, called its left lobe, partly overlies the stomach. The liver secretes a fluid called bile, which is used to aid the digestion of the food. The bile, when not required, is stored in a small bag on

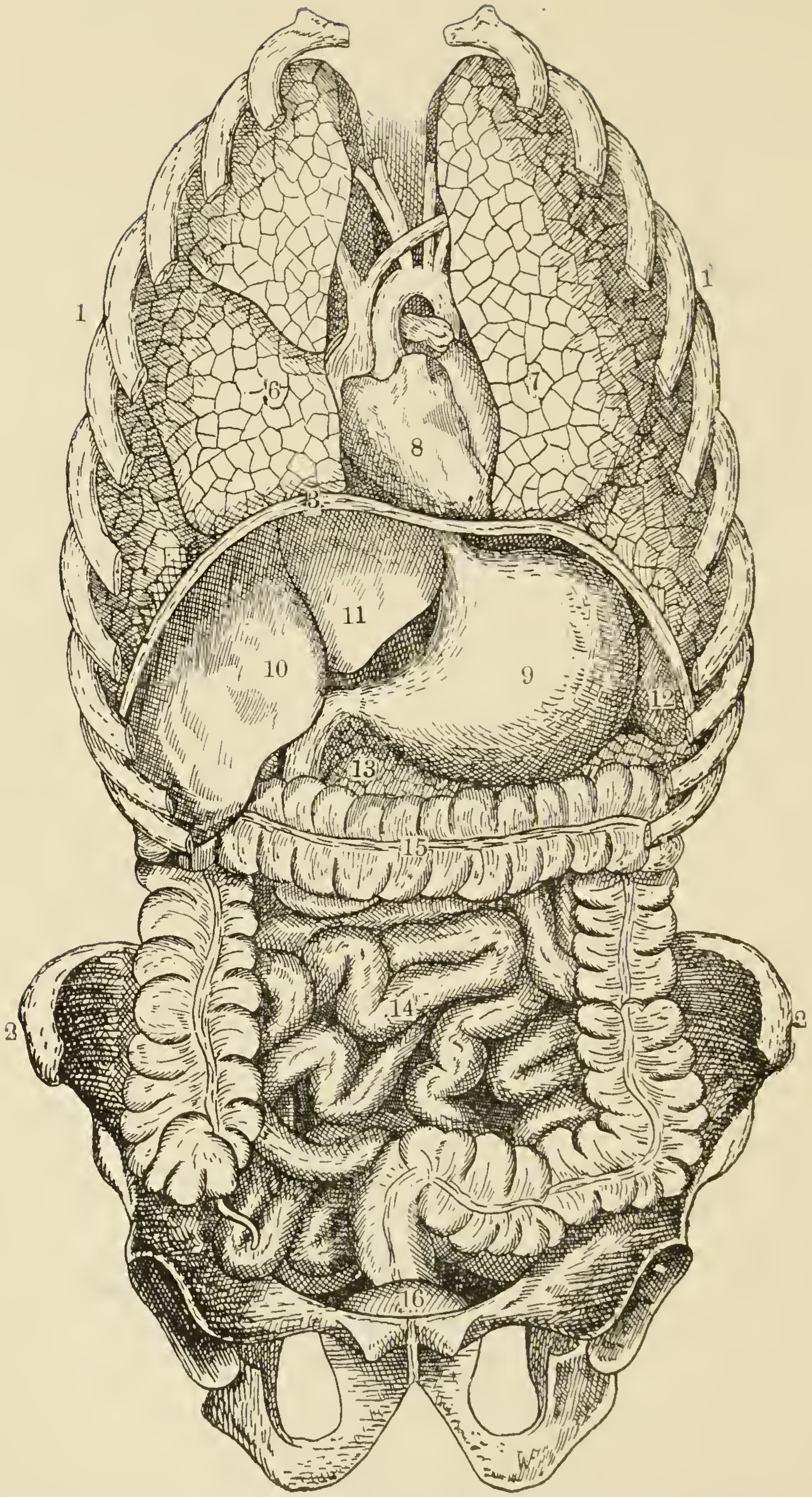


FIG. 119.—The viscera of the thorax and abdomen, viewed from the front. 1, ribs, the front portions of which, together with the sternum, have been removed; 2, bones of the pelvis; 3, diaphragm; 4, thorax; 5, abdomen; 6, right lung; 7, left lung; 8, heart; 9, stomach; 10, right lobe of the liver; 11, left lobe of the liver, turned up; 12, spleen; 13, pancreas; 14, small intestine; 15, large intestine; 16, bladder. (From Furneaux's "Elementary Physiology.")

the under surface of the liver called the **gall-bladder**, and from this it passes by a tube into the upper part of the small intestine.

The **pancreas**, or **sweetbread**, is an organ shaped like the head of a hammer, which lies partly behind and below the stomach. It also secretes a fluid, the pancreatic juice that is poured into the intestine to aid in digestion.

The **spleen** is a dark red body placed behind and to the left of the stomach. It is connected in some way with the production of white corpuscles and the purification of the blood.

The **kidneys** are two oval or bean-shaped organs about four inches long which lie behind the intestines at the back of the abdomen on each side of the spinal column. They are embedded in the fat of the loin, the part of the body beneath the last rib at the back. The function of the kidneys is to excrete certain impurities that have accumulated in the blood. These impurities, dissolved in water, are conveyed from the kidneys by two tubes called the **ureters.** The ureters pass to a membranous bag known as the **bladder**, and into this they convey continuously the urine as it is secreted by the kidneys. From the bladder, which lies towards the front in the lower part of the abdomen, a tube starting at its lower end, and called the **urethra**, passes to the outside.

The **limbs** of the human body consist of two pairs, the upper limbs and the lower limbs. The upper limbs, or **arms**, are connected with the upper part of the trunk at the shoulder-joint, and the lower limbs, or **legs**, are united to the lower part of the trunk at the hip-joint.

The whole body is covered with a soft, slightly hairy **skin**, with longer and stronger hairs on the head. Beneath the skin we find the flesh or **muscles** attached to the bones, and these are the agents by means of which the bones are moved at the joints.

After reading the foregoing general description of the

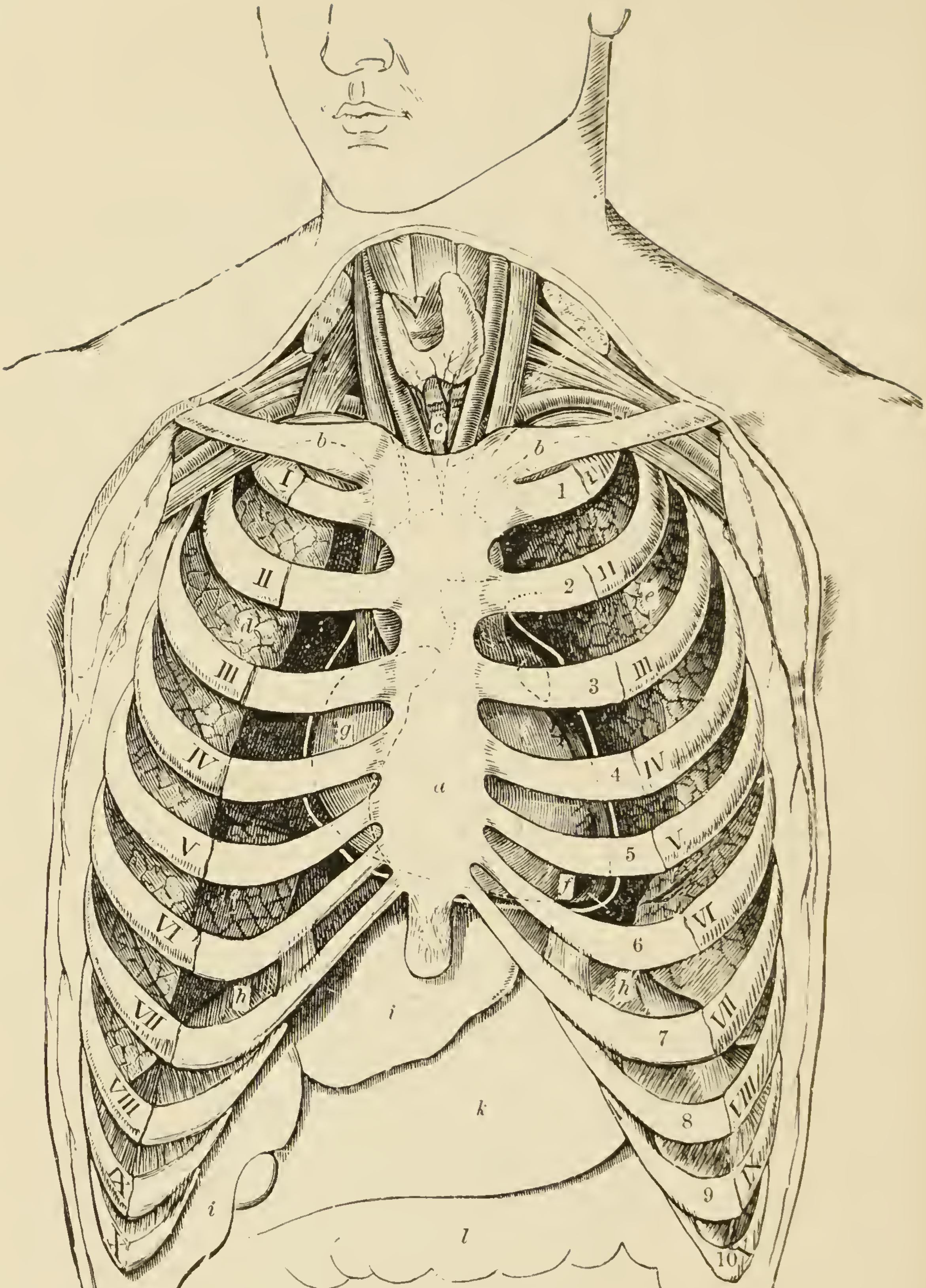


FIG. 120.—The organs of the chest. I to X, ribs; 1 to 10, rib cartilages on the left; *a*, breast-bone; *b*, collar-bone (the muscles are left out in order to show the organs inside the chest); *c*, windpipe; *d*, right lung; *e*, left lung; *f*, apex of the heart; *g*, base of the heart; *h*, upper surface of the diaphragm; *i*, liver; *k*, stomach; *l*, intestine. The last three organs are beneath the diaphragm, and therefore belong to the abdomen. (From Quain's "Anatomy.")

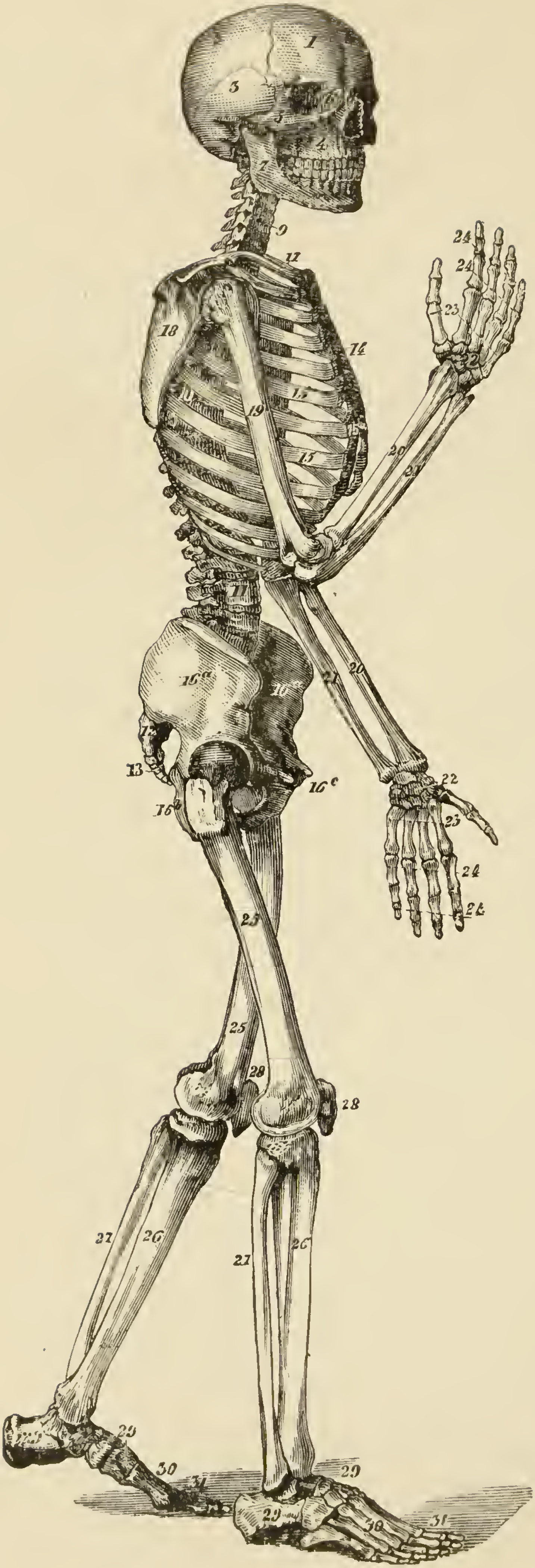
body, and carefully studying the figures illustrating it, the student may now consider in some detail the bony framework on which the body is built.

76. The Human Skeleton.—The whole of the bones of an animal in their natural position form the **skeleton.** The human skeleton consists of rather more than 200 bones, variously united together so as to form **joints** or **articulations,** at which motion can take place. The chief *uses* of the bones are: (1) to give stability to the shape of the body; (2) to support the soft parts; (3) to protect important organs; (4) to give attachment to the muscles; and (5) to act as levers when force is exerted upon them by attached muscles.

With the aid of the description and figures in the text and a set of dried bones or a skeleton, the reader will now be able to learn the form and position of the chief bones.

The principal parts of the skeleton are: (1) the spinal column, with the appended thorax; (2) the skull; (3) the bones of the upper limbs or arms, with the scapula (shoulder-blade) and clavicle (collar-bone), to which each limb is connected above; (4) the bones of the legs, with the connected pelvic bones at the upper end.

77. The Vertebral Column.—The vertebral column, which is also known as the **backbone** or **spinal column,** consists of a pillar of thirty-three superposed bones, each of which is called a **vertebra** (pl. *vertebræ*). These vertebræ are named and grouped according to their position, as follows: 7 cervical or neck vertebræ; 12 dorsal or thoracic vertebræ; 5 lumbar vertebræ; 5 sacral vertebræ; and 4 coccygeal vertebræ. Only 26 of these, however, in the adult state are separate, for the five sacral vertebræ are then fused together to form one bone called the sacrum, and the four last are fused together to form the coccyx. Each of the separate vertebræ, except the two upper ones, is constructed on the same plan; for each consists in front of



1. Frontal bone.
2. Parietal bone.
3. Temporal bone.
4. Upper jaw (maxilla).
5. Cheek-bone (malar bone)
6. Lachrymal bone.
7. Lower jaw (mandible).
8. Nasal bone.
9. Cervical vertebræ.
10. Thoracic vertebræ.
11. Lumbar vertebræ.
12. Sacral bone.
13. Coccygeal bone.
14. Sternum.
15. Ribs.
16. *a-c.* Pelvis.
17. Clavicle.
18. Scapula.
19. Humerus.
20. Radius.
21. Ulna.
22. Carpal bones.
23. Metacarpal bones.
24. Phalanges.
25. Femur.
26. Tibia.
27. Fibula.
28. Patella.
29. Tarsal bones.
30. Metatarsal bones.
31. Phalanges.

Fig. 121.—Human skeleton. (From Schmeil's "Text-book of Zoology.")

a short cylinder or disc called the **body**, to the back of which a ring of bone, called the **neural arch**, is attached (Fig. 123). The neural arch bears three projections or processes, two lateral or side processes, and one **spinous** process. These processes serve as places of attachment for ligaments and muscles, and in the case of the dorsal vertebræ they also serve, together with the bodies of the vertebræ, as points of attachment for the ribs behind. Between the bodies of the vertebræ are pads of cartilage or gristle, known as **intervertebral cartilages.** These serve, in binding the vertebræ together, in giving a certain amount of elasticity to the backbone, and also as buffers to distribute jars and shocks.

The first cervical vertebra, known as the **atlas**, because it bears the head, differs from those just described. It has no body, but consists of a thin ring of bone bearing on its upper surface two articular surfaces, on which rest two knobs or condyles of the occipital bone at the back of the head. The second vertebra is called the **axis**, because it is so connected with the first as to allow the head and first vertebra

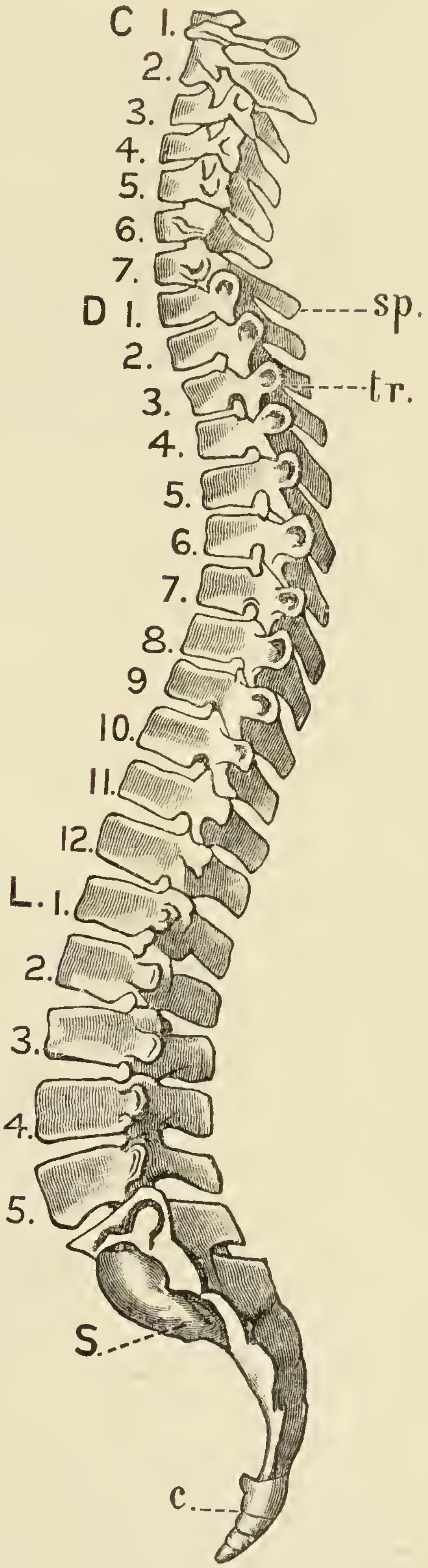


Fig. 122.—The vertebral column, viewed from the left side. C 1, first cervical vertebra; D 1, first dorsal vertebra; L 1, first lumbar vertebra; S, first sacral vertebra; *c*, first coccygeal vertebra.

to turn from one side to the other. This is effected by a process called the **odontoid peg**, which rises from its body and fits into a small ring of the atlas, formed by a strong fibrous band which passes across behind the anterior arch and in front of the neural ring (the dotted line in Fig. 125).

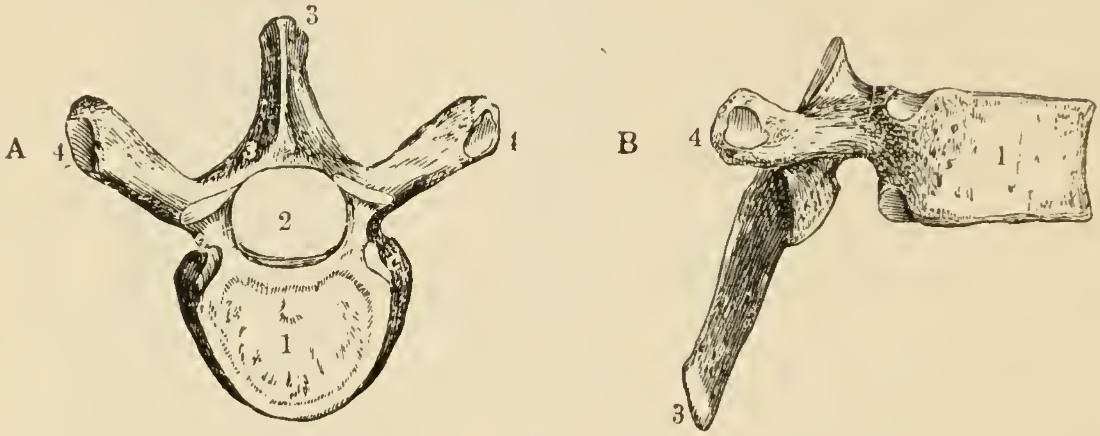


FIG. 123.—A dorsal vertebra (6th). A, viewed from above; B, viewed from the right side. 1, body; 2, spinal cavity; 3, spinous process; 4, lateral processes. (From Quain's "Anatomy.")

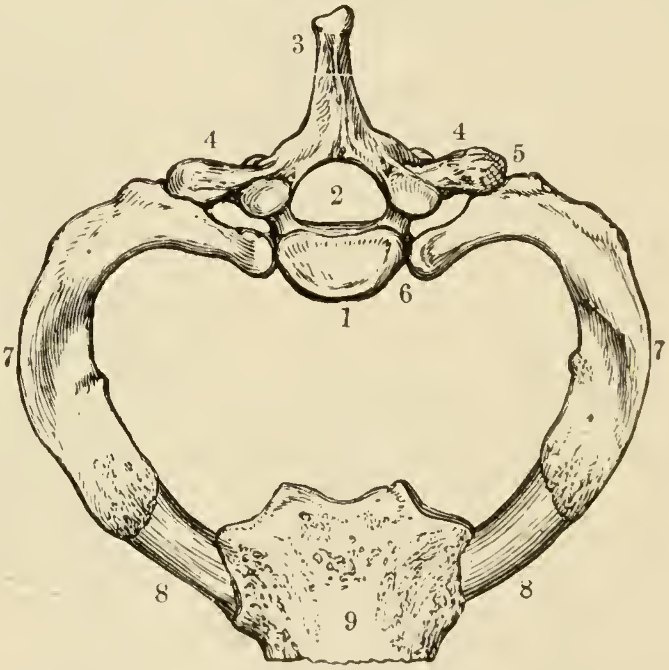


FIG. 124.—First dorsal vertebra, with the first pair of ribs, and a portion of the sternum. 1, body of the vertebra; 2, spinal cavity; 3, spinous process; 4, lateral processes; 5, articular facet of lateral process; 6, articular facet for the head of the rib (these two facets form, with the rib, movable joints); 7, ribs; 8, cartilage or gristle connecting the ribs with the sternum; 9, sternum, or breast-bone. (From Quain's "Anatomy.")

It will be now understood how the spinal rings or neural arches of the vertebræ, placed one above another, form a long bony tube or canal. In this **spinal canal** lies a long, roundish mass of nervous matter, called the **spinal cord.** From the spinal cord there arises, by two roots on each side, thirty-one spinal nerves, which pass out from the cord at intervals left at the sides between the vertebræ, and then ramify backwards and forwards in various parts of the body.

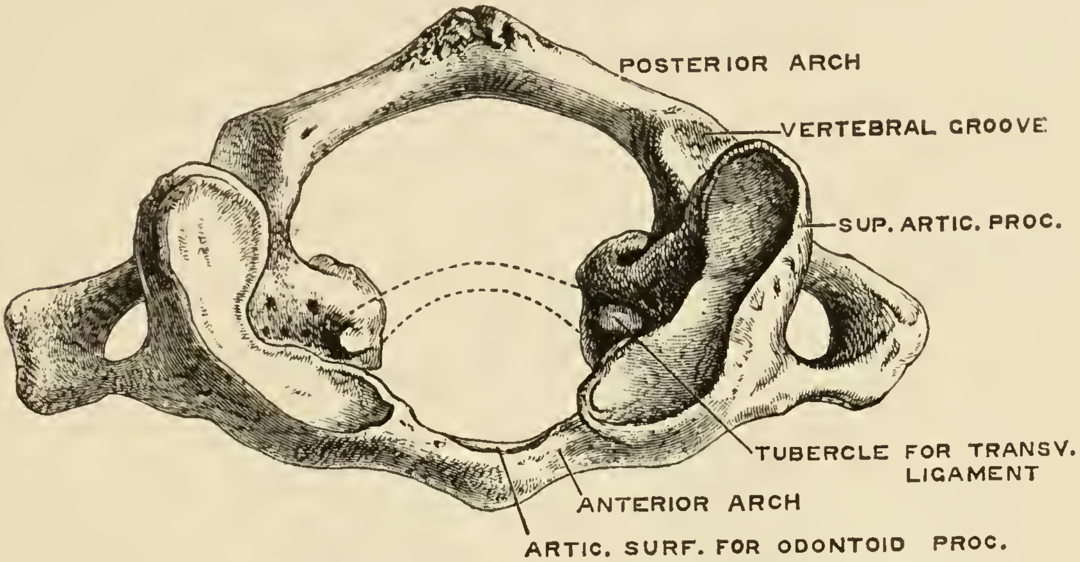

POSTERIOR ARCH
VERTEBRAL GROOVE
SUP. ARTIC. PROC.
TUBERCLE FOR TRANSV. LIGAMENT
ANTERIOR ARCH
ARTIC. SURF. FOR ODONTOID PROC.

FIG. 125.—Atlas, from above. Position of transverse ligament indicated by dotted line (D. Gunn). (From Quain's "Anatomy.")

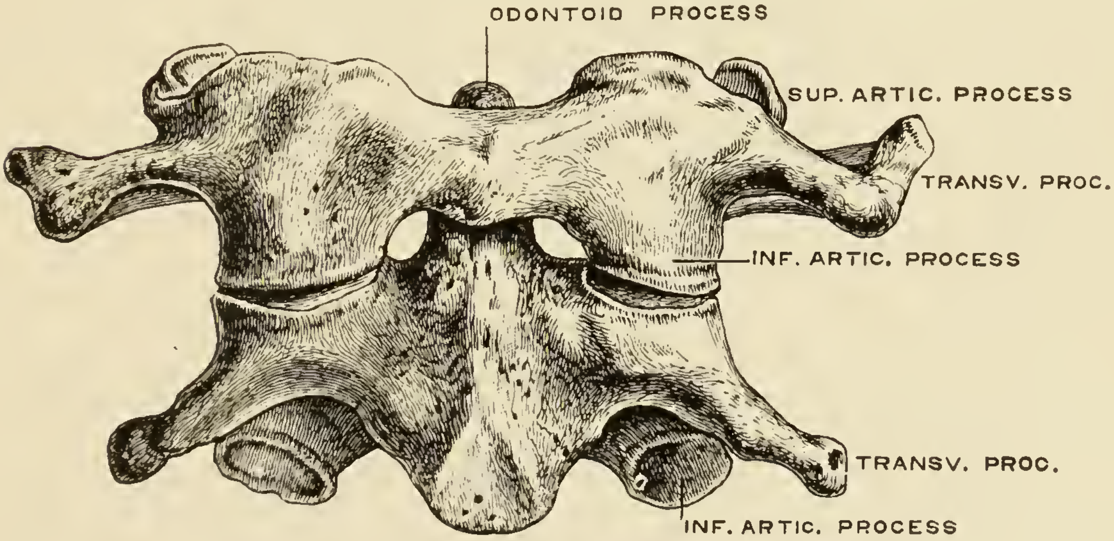


FIG. 126.—Atlas and axis, from before (drawn by D. Gunn). (From Quain's "Anatomy.")

An examination of Fig. 122 shows that the spinal column presents in its course a sinuous curvature, forwards in the neck and loins, and backwards in the dorsal and sacral regions. Owing to this curvature the weight of the trunk and head is well distributed, partly in front and partly behind. At its lower end it is itself supported between the hip-bones, through which the weight of the body is transmitted to the legs.

78. The Thorax.—The chest, or thorax, is a conical bony cage formed by the twelve dorsal vertebræ at the back, the breast-bone or sternum in front, and the twelve curved bones on each side, called the ribs (Fig. 127). Each rib is attached behind to the corresponding dorsal vertebra at two places (Fig. 124), so that each dorsal vertebra is united to a pair of ribs. The first seven ribs are connected in front to the sternum by a separate piece of cartilage—**costal cartilage** (Lat. *costa*, "a rib"). The next three are connected to each other by their own cartilages, and then to the cartilage of the seventh pair. The last two ribs, the

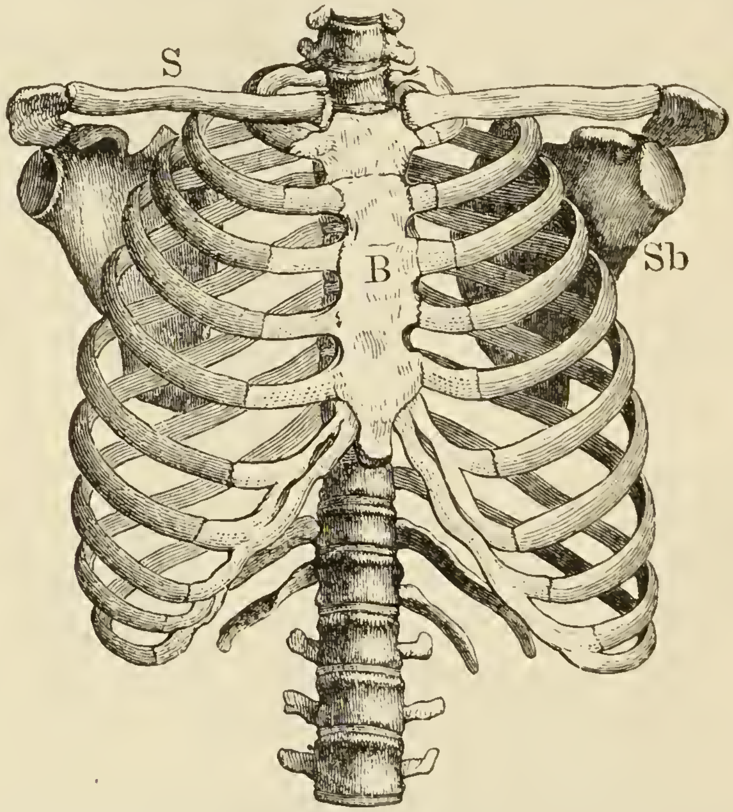


FIG. 127.—Front view of thorax. B, sternum, or breast-bone ; S, clavicle, or collar-bone ; Sb, scapula, or shoulder-blade. (The costal cartilage connecting the ribs with the sternum is of lighter shade.)

eleventh and twelfth, are shorter than the others, and not connected at all in front, terminating in the muscular wall of the belly, and being called the "floating ribs." The ribs do not lie horizontally, but incline downwards somewhat. In life the intervals between the ribs, called the **intercostal spaces**, are filled in by flat muscles, called the **intercostal muscles.**

The **sternum** is a flat bone shaped something like a dagger, with the broad end nearest the neck. The cartilages of the first seven ribs meet it on each side, but its narrow end reaches beyond the attachment of the seventh costal cartilage.

79. The Skull.—The bones of the head form the **skull**, and the skull rests upon the topmost vertebra, the atlas. It may be divided into two parts, the **cranium** and the **face.**

The cranium is the large hollow bony case that contains the brain. It consists of eight bones firmly locked together by saw-like edges called **sutures.**

The eight bones of the skull are—

(*a*) The frontal bone, forming the front of the cranium.

(*b*) The two parietal bones, forming part of the side-walls and the roof.

(*c*) The two temporal bones around the temples.

(*d*) The occipital bone, forming the back and a part of the floor or base. Its lower portion is perforated by a large hole called the **foramen magnum**, through which the brain unites with the spinal cord. On each side of this hole is a rounded knob, or condyle, and these fit into two depressions on the atlas, so as to form the articulation that allows the head to nod.

(*e*) The sphenoid bone, forming a part of the base towards the front.

(*f*) The small ethmoid bone, forming part of the base between the sockets of the eyes.

The bones of the face are fourteen in number, and all these, except the lower jaw or mandible, are firmly united to the bones of the skull. These fourteen bones of the face are—

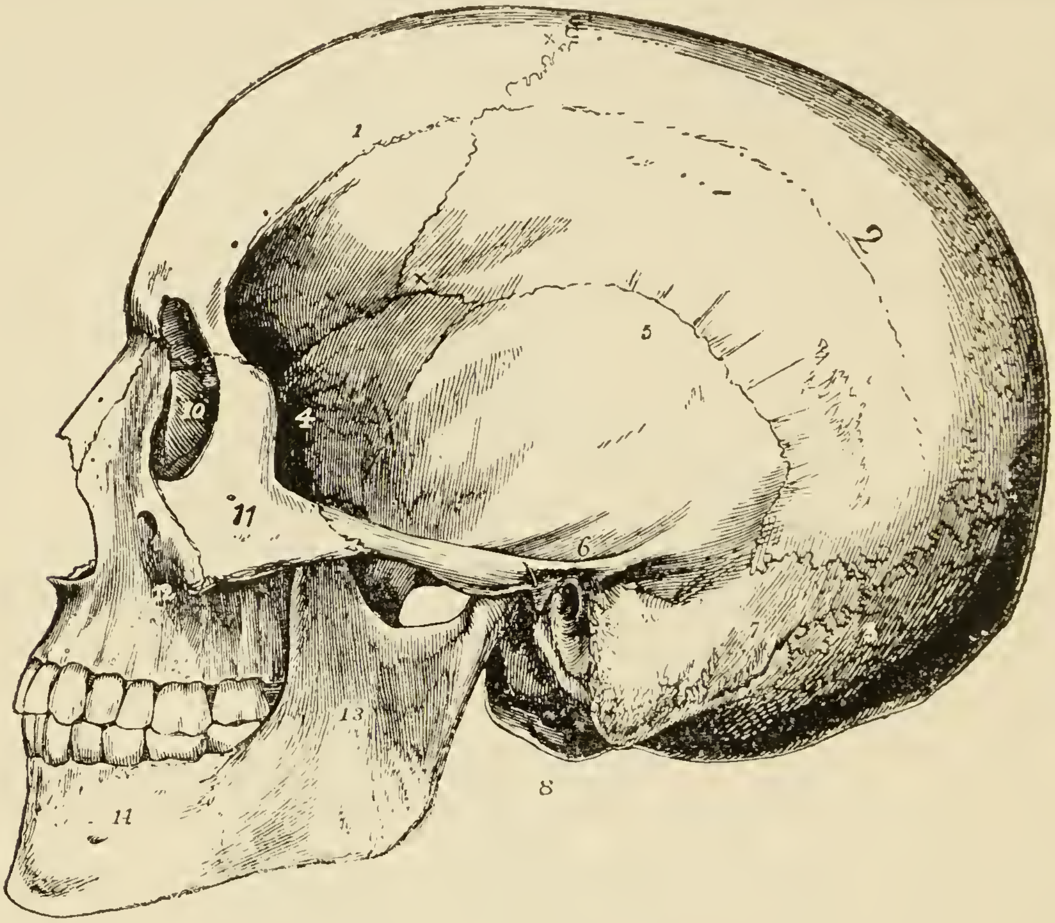


FIG. 128.—Side view of the skull. 1, frontal bone; 2, parietal bone; 3 and 8, occipital bone; 4, wing of the sphenoid bone; 5, 6, and 7, temporal bone; 10, lachrymal bone, in the inner wall of the orbit; 11, malar bone; 12, superior maxillary; 13 and 14, inferior maxillary. (From Quain's "Anatomy.")

(*a*) Two superior maxillary bones, forming the upper jaw and a portion of the palate, or roof of the mouth.

(*b*) Two palatal bones, forming the hinder part of the palate, and united in the middle.

(*c*) Two small nasal bones between the sockets of the eyes, and forming the upper hard bridge of the nose.

(*d*) Two small lachrymal bones containing ducts that lead tears from the eyes to the nose.

(*e*) Two inferior turbinate bones, one in each nostril chamber above the hard palate.

(*f*) One small vomer bone, forming a middle partition in the nasal cavity.

(*g*) Two malar or cheek-bones, forming the prominences of the cheek and sending an arch (the zygomatic arch) backwards to join the temporal bone.

(*h*) The inferior maxillary bone, or mandible, forming the lower part of the chin and lower parts of the cheeks. This is the only bone in the head which is movable. Its hinder and upper part ends in two round processes (condyles), each of which fits into a hollow of the temporal bone under the ends of the zygomatic arch of the malar bone (compare Figs. 128 and 129). There is thus formed on each side, between the lower jaw and the temporal bones, a hinge-joint, the movements of the jaw being brought about by muscles that form the soft part of the cheek and part of the neck. The lower jaw is not only capable of movement upwards and downwards, but to a slight extent backwards and forwards and from side to side, thus enabling us to bite and grind our food.

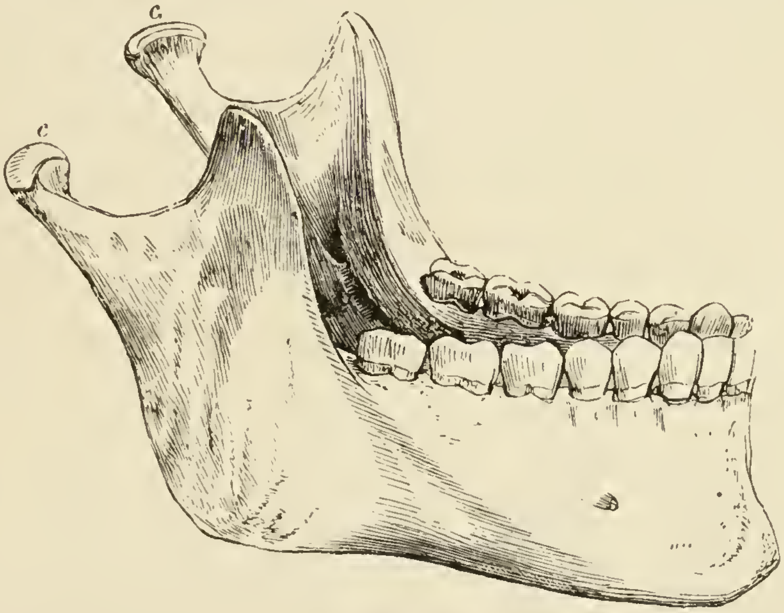


FIG. 129.—The inferior maxillary bone. *c*, the condyles, which articulate with the temporal bones. (From Quain's "Anatomy.")

Embedded in sockets in the upper and lower jaw-bones are teeth. Each tooth consists of a visible part called the **crown**, and one or more **fangs** buried in the socket (Fig. 130). In the adult the full number of teeth is thirty-two, sixteen in each jaw. The teeth are similar in character in each jaw, and in each half of each jaw; but each side of the jaw has teeth that differ in form, and that are called by different names (see Fig. 130, and examine the mouth of an adult, or your own mouth before a looking-glass). The front teeth, or four central teeth of each jaw (two on each side of the middle line), have sharp chisel-like edges, and are called **incisors**; and on each side of the incisors there is, in each half of the jaw, a longer pointed tooth called the **canine** tooth (Lat. *canis*, "a dog"). The two upper canine teeth are sometimes called the "eye-teeth." Behind the canine teeth on each side are teeth with two cusps or points, called the **bicuspid** or **pre-molar** teeth. Behind the bicuspid teeth on each side are broad teeth with four or five cusps, which are called **molar** teeth. The last of the molars, or grinding teeth, does not often appear until after the twentieth year, and these last molars are known as **wisdom** teeth.

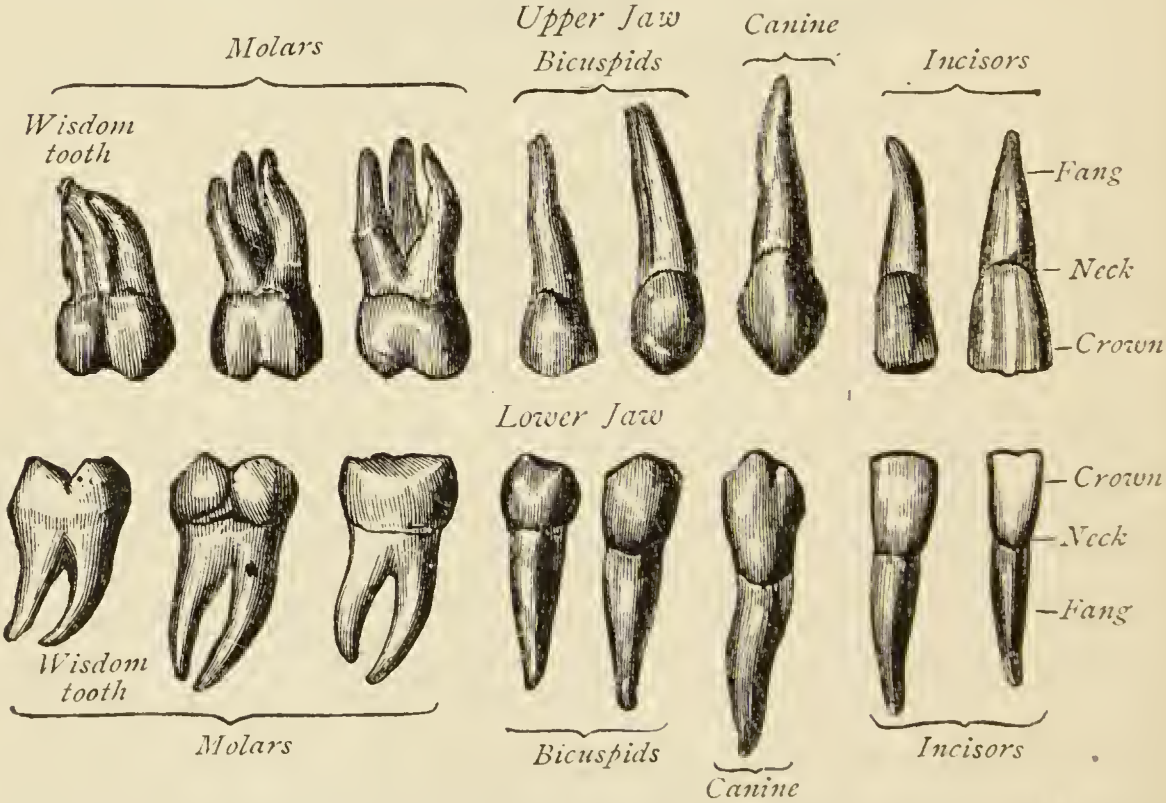


FIG. 130.—The permanent teeth, removed from the jaws (From Wilson's "Manual of Health Science.")

The following table, or dental formula, tabulates the number and arrangement of the teeth, the initials indicating the kind of teeth, those of the upper jaw being written like the numerator of a fraction, and those of the lower jaw as the denominator, while a dash or thin line separates the teeth of each half of each jaw :—

$$\mathrm{I}\,\frac{2-2}{2-2},\ \mathrm{C}\,\frac{1-1}{1-1},\ \mathrm{P}\,\frac{2-2}{2-2},\ \mathrm{M}\,\frac{3-3}{3-3} = 32$$

The teeth above described are known as the **permanent** teeth, for they displace and follow a set of teeth that appear in early life, known as the **milk teeth.** The milk teeth are only twenty in number, as they do not include any true molars.

80. The Arms.—Each upper limb, or arm, consists of shoulder, upper arm, forearm, wrist, and hand. The bones of the shoulder are the **clavicle**, or collar-bone, and the **scapula**, or shoulder-blade, and the two together form the **shoulder girdle.** The **clavicle** is a long bone shaped like an italic ∽ that passes from its articulation with the top of the sternum outwards to a process of the scapula (Fig. 131), as may be readily traced on your own body. It serves to keep the shoulders from falling forward. The scapula is a flat, triangular bone with ridges, and lies on the back of the thorax, where it has freedom of motion. At its outer angle it has a shallow hollow, lined with cartilage—the glenoid cavity—into which the rounded head of the **humerus** is fixed by ligaments to form the shoulder-joint — a ball-and-socket joint that allows free movement in various planes. The **humerus** is the long round bone of the upper arm. As just mentioned, it articulates above by its rounded head with the scapula. Its lower end is spread out to form on the outer and inner sides condyles with which the two bones of the forearm are articulated. The bones of the forearm are the **ulna** and the **radius.** The ulna is the inner bone of the forearm (little-finger side), and at its upper end is deeply grooved from side to side to articulate with the inner condyle of the humerus. A projection called the **olecranon process**

forms the sharp prominence of the elbow. It thus forms with the humerus a **hinge joint** (a joint like the hinge of a door, that allows motion in one plane only), which allows a movement of flexion and extension, while the olecranon process prevents the forearm from bending backwards.

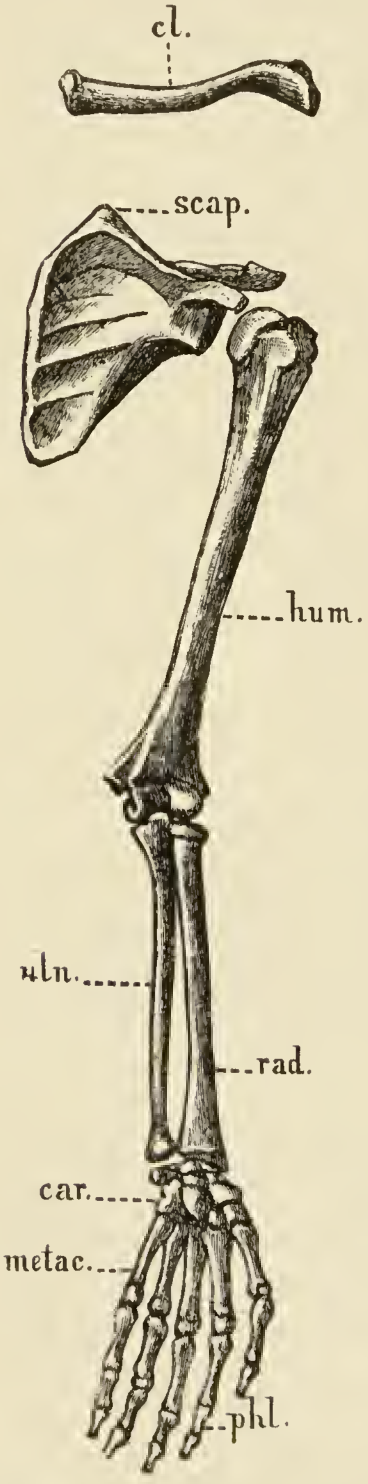


Fig. 131.—Bones of the upper limb. (From Notter and Firth's "Practical Domestic Hygiene.")

The radius is the outer bone of the forearm (thumb side), and has at the upper end a shallow cup that articulates with the humerus. Its lower end is enlarged, and contains on its inner side a slight hollow into which the lower narrow end of the ulna fits. The articulation of the radius is such that it can roll partly over the ulna, carrying with it the hand. The movement of the radius over the ulna brings about **pronation**, the hand being palm downwards. When the radius is rolled back again, the two bones become uncrossed and the palm is uppermost, a position termed **supination** of the hand.

The **carpus**, or wrist, consists of two rows of small bones, four in each row, with the upper row united to the radius. These small bones are bound together by ligaments, and allow of a slight movement over one another (Figs. 121 and 131). The second row of carpal bones articulates with the fine bones in the palm of the hand. These are termed **metacarpal bones**, and should be traced from the wrist to each digit. At their outer end they are united by a transverse ligament.

The bones of the digits, or fingers, called **phalanges**, are united to the metacarpal bones of the palm. There are three phalanges in each finger, and two in the thumb. The joint between the metacarpal bones and the first of the phalanges of the thumb is a ball-and-socket joint, and allows of a great degree of motion, so that the thumb can be brought into opposition to the fingers, and the hand is thus able to grasp objects.

81. The Lower Limbs.—Each lower limb consists of haunch or hip, femur or thigh, leg, ankle, and foot. The hip-bone, or **pelvic girdle**, on each side consists of a strong bony arch springing from the sacrum and passing downwards and forwards round the lower part of the trunk, to meet its fellow on the other side in front. The two hip-bones, therefore, with the sacrum wedged between, form a complete ring or girdle of bones that encloses a cavity, and receives the weight of the upper part of the body (Figs. 121 and 132).

Each hip-bone is known as the **os innominatum**, or innominate bone, and consists, until about the eighteenth year, of three bones termed the **ilium**, **ischium**, and **pubes** (Fig. 132), the ischium being the lower portion on which one rests when sitting. A pad of cartilage unites the two pubic bones in front. In the lower and front part of the great hip-bone is a large foramen, or hole, through which nerves and blood-vessels pass, while on each side is a large, deep cavity called the **acetabulum.**

The acetabulum receives the round head of the long thigh-bone into its deep socket, and in the living body the head is kept in position by strong ligaments. This ball-and-socket joint, being much deeper than the one at the shoulder, does not allow the same extent of movement as exists at the shoulder. The **femur**, or thigh-bone, is the longest bone in the body. Its lower end is expanded into two condyles, which articulate with the inner bone of the leg proper. The leg below the knee has two bones, the inner, called the **tibia**, and the outer, called the **fibula** (Fig. 121). The tibia is the larger of the two, and articulates above with the femur to form the hinge joint called the knee-joint.

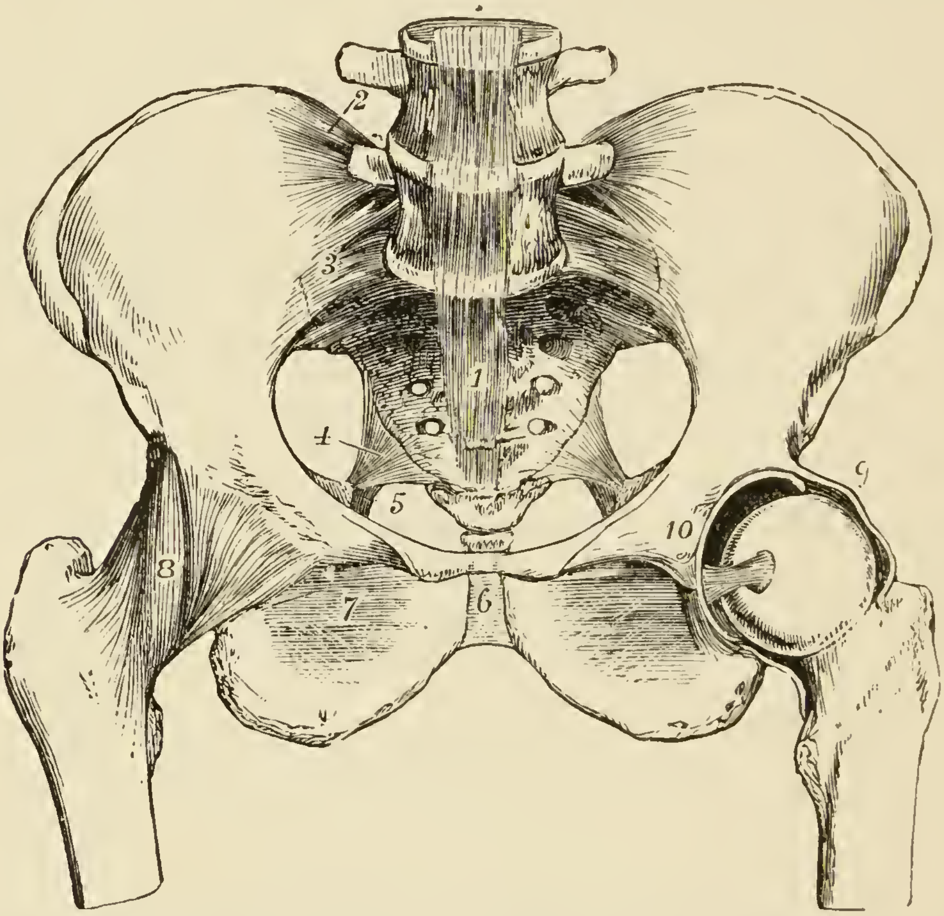


FIG. 132.—The joints of the pelvis. 1, ligament of the vertebræ; 2, 3, 4, 5, 6, 7, and 8, other ligaments; 9 and 10, ball-and-socket joint of the hip, in part dissected to show the synovial cavity, and also the ligament (*ligamentum teres*) which connects the ball of the femur with the interior of the acetabulum. (From Quain's "Anatomy.")

In front of the knee-joint, within a tendon, lies the small flat bone called the **patella**, or knee-cap.

The foot, like the hand, consists of three parts: ankle, or **tarsus**, **metatarsus**, and **digits**, or toes. The tarsal bones are seven, the largest called the **os calcis**, or heel-bone, projecting backwards to form the heel. The five metatarsal bones succeed those of the tarsus, and form the sole of the foot. To these succeed the fourteen phalanges of the toes, each toe having three phalanges, except the great toe, which has only two. The foot has an arched form, the bones being supported by strong ligaments, and this arched form is peculiar to man. It rests on the ground in three places—the heel, the ball of the great toe (the articulation of the great toe with the inner metatarsal bone), and the ball of the little toe (the articulation of the little toe with the outer metatarsal bone) (Fig. 121). It is thus admirably adapted for supporting the body and furnishing a certain amount of elastic spring.

The articulation between the great toe and its metatarsal bone is a simple hinge joint, so that it cannot be opposed to the other toes in the same way as the thumb can be opposed to the fingers.

82. Structure of a Joint.—A joint, or **articulation,** is the union of two bones, and the surfaces that come in contact are known as **articular** surfaces. **Imperfect joints** either allow no movement at all, as in the case of the union by sutures of the bones of the cranium, or only a very limited movement, like the joints between the vertebræ. **Perfect joints** are those in which the ends of two opposed bones whose opposing surfaces are covered with **cartilage,** can freely move over one another within certain limits. The limits are determined, in the main, by the shape of the bones entering into the joint, and by the **ligaments** that pass from one bone to the other. Ligaments are strong, inelastic bands of white fibrous tissue passing from bone to bone at the joints (Fig. 132). Lining the ligaments, and extending some distance over the articular cartilage of the bones, there is also at each perfect joint a thin smooth membrane (the synovial membrane) that secretes a lubricating fluid called **synovia** (see Fig. 140).

The most important kinds of perfect joints are—

(*a*) Hinge joints, such as those in the fingers, at the elbow, knee, and ankle, where rounded surfaces work in corresponding hollows, and allow movement in one plane only, these being either bending (flexion) or straightening (extension).

(*b*) Ball-and-socket joints, such as those at the shoulder and hip, where a globular surface fits into a cup-shaped cavity, and allows movements in many planes. The socket at the shoulder is shallower than at the hip, and thus allows to the arm and hand a wider sweep of movement than is allowed to the leg and foot.

(*c*) Pivot joints, where one bone rotates to some extent round another, as the atlas with the skull round the axis in turning the head (Fig. 126), or the radius round the ulna in turning opposite surfaces of the hand upwards.

(*d*) Shifting joints, where there is only a small gliding motion between the ends of the opposed bones, as is the case at the wrist and ankle.

83. Structure of Bone.—It should be noted that bones are living structures provided with blood for their nutriment. They are covered, except where tipped with articular cartilage, by a vascular membrane called the **periosteum.** They consist partly of organic matter, and partly of inorganic matter. The organic matter consists of cells and matter derived from the cells, while the inorganic material deposited among the living matter consists mainly of mineral salts, called calcium carbonate and tricalcium phosphate. The inorganic mineral matter may be dissolved out by immersing a fresh bone in dilute hydrochloric acid. The organic matter then remains in a soft and pliable condition. The mineral matter may be obtained separately by burning away the organic matter on a red fire. It then readily falls to powder as bone-ash.

A long bone like the humerus or femur is found, when cut through, to contain a cavity filled with marrow, a reddish tissue containing blood-vessels and much fat. The outer part of such a bone, especially in the shaft, is formed of harder and denser bone than the spongy bone making up the bulk of the ends.

CHAPTER XV.

THE MUSCULAR AND NERVOUS SYSTEMS.

84. Muscles.—The jointed bony system called the skeleton is clothed or covered in most parts by what is commonly called **flesh.**

The flesh really consists of a number of separable organs called **muscles,** the separate muscles being covered by a fibrous sheath termed the **fascia.** About 240 such separate muscles are found in the human body, and of these rather more than half belong to the head, neck, and trunk, and the remainder to the limbs. They are of various shapes and sizes.

An ordinary muscle is a red fleshy mass made up of bundles of fine fibres surrounded by thin connective tissue that binds the bundles together and a sheath of connective tissue that encases the whole muscle. Each muscle is supplied with blood-vessels and nerves. Muscles are of various shapes but usually larger in the middle than at the ends, where they generally terminate in one or more whitish fibrous cords termed sinews, or **tendons.**

Tendons, or sinews, form the tapering ends of muscles, and serve to connect the muscles to the bones. They often occur as white glistening cords. They must not be confused with the **ligaments,** which are the strong bands passing from bone to bone and keeping the bones in place at the joints. The tendon (or tendons) of one end of a muscle is fixed to one bone and the tendon at the other end to another bone, a joint lying between. A muscle has these two attachments to the skeleton. In some cases it is the muscle itself that is fastened to the bone. The mass of the muscle between the attachments at each end is called the **belly** of the muscle, and the point at which the muscle is fixed to the less movable bone is called the **origin** of the muscle, while the point of attachment to the movable bone or part is called the **insertion** of the muscle.

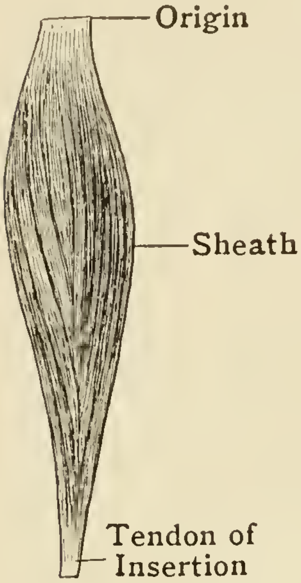


FIG. 133.—A typical muscle.

The reader should obtain the leg of an animal that has been killed—a rabbit or a cat. On stripping off the skin and removing the superficial fascia, separate muscles may be found attached at each end by tendons. Remove one of these, and separate it into its fibrous bundles by means of a knife and needles. Note the blood-vessels and nerves. To see the separate fibres and the more minute structure of the muscle requires the aid of a microscope.

The various joints of the skeleton allow the bones to be bent and moved in various ways when force is exerted on one or another in a suitable way. This force is supplied by the shortening or contraction of the muscles. When a nervous impulse reaches such a muscle as we have described, it shortens or contracts in length, but at the same time swells up towards the middle so as to keep the same volume. It thus draws the insertion, with the parts to which it is attached, nearer to the fixed origin. It should be noted that a muscle can pull, but not push, and that motion in two different directions can only be produced by opposing muscles.

Muscles are generally divided, according as they work or not under the influence of the will, into two classes, termed **voluntary muscles** and **involuntary muscles.** The

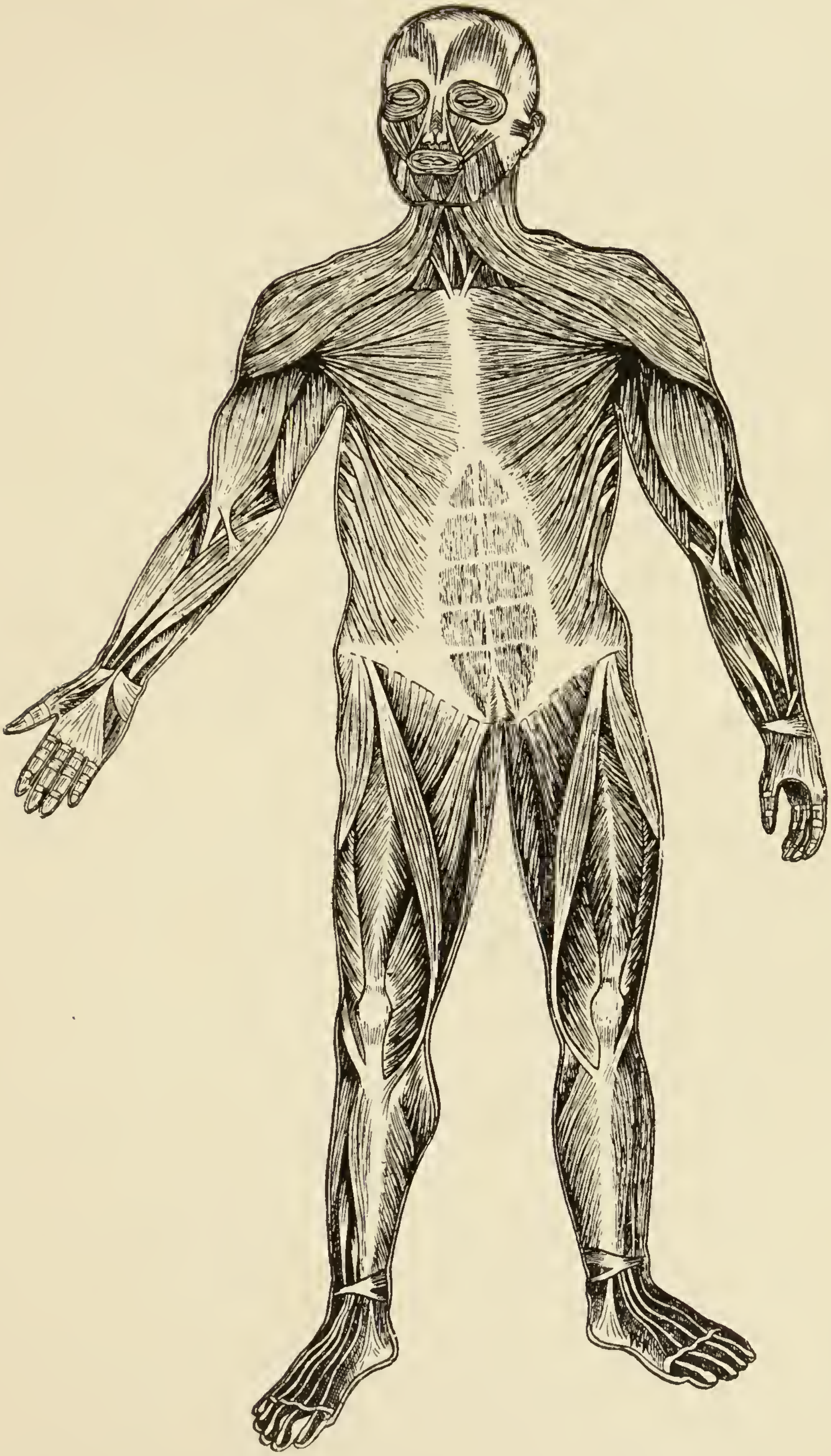


FIG. 134.—The superficial muscles of the body, viewed from before. (From Furneaux's "Elementary Physiology.")

voluntary muscles are those which act under the control of the will. These muscles form the bulk of the fleshy parts of the limbs and trunk, and as they consist of fibres that show transverse markings, or striæ, a voluntary muscle is also known as a **striated muscle.** The involuntary muscles are those which carry on their work without the action of the will. Such muscles form the substance of the heart, and are found in the walls of the stomach, intestines, and blood-vessels. By their action, they force along the contents of these organs. As an involuntary muscle is formed of spindle-shaped cells that show no transverse striæ, it is known as a **non-striated muscle.** Heart muscle, though involuntary, consists of quadrate cells that show faint striation.

Many muscles are arranged so as to oppose each other in action, so that when one produces motion in one direction, another brings the part moved back into place again.

To understand the action of the muscles the reader must revise his knowledge of levers.

85. Levers.—A lever is a rigid bar or rod capable of turning about a fixed point called a **fulcrum.** The portion of the lever measured from the fulcrum to the power is called the **power arm**; and the portion of the lever measured from the fulcrum to the resistance or weight is called the **weight arm.**

Try the following experiment : arrange a lever so as to turn about a point C as in the figure. When the arms are equal, it will be found that a weight at W will be balanced by an equal weight at P. But when a weight of 2 lbs. say is placed at W, it will be found that 1 lb. at P will balance it, if the arm PC is twice the arm WC. If the power arm be made three times as long as the weight arm, then a weight at W will be balanced by

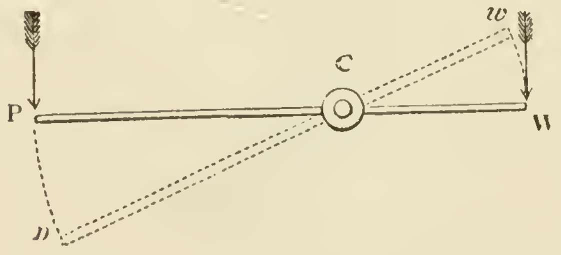


FIG. 135.—A lever turning about a fulcrum at C. (From Tate's "Elements of Mechanism.")

one-third the force or weight at P. And generally we shall find—

Power × its arm = weight × its arm.

On moving the lever from its position, it will be found, however, that when the force at P is less than the resistance or weight at W, P will move through a corresponding greater distance than W. In the figure, the small arc P*p* is twice as great as the arc W*w*. Conversely, when the weight arm is the longer, the power will be correspondingly greater, and move through the less distance, and the motion of power and resistance take place in the same time. And generally, therefore—

Power × space it passes thro' = weight × space it passes thro'.

We thus see why it is possible to overcome great resistances by a lever when we exert a small force through a great distance, and why it is also possible with a lever to move a small weight rapidly through a great distance by a great power moving through a small distance.

Levers are often, for the sake of reference, divided into three classes, according as the fulcrum, weight, or power is in the middle.

(1) When the fulcrum is between the force or power and the resistance or weight, the lever is said to be of the **first order.**

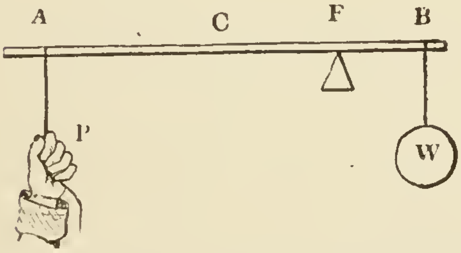


FIG. 136.—Lever of first order (fulcrum in the middle). (From Tate's "Mechanism.")

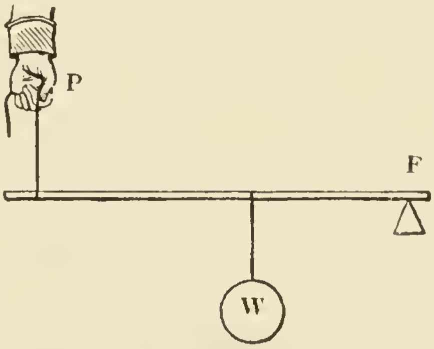


FIG. 137.—Lever of second order (weight in the middle). (From Tate's "Mechanism.")

(2) When the resistance or weight is between the power and the fulcrum, the lever is of the **second order.**

(3) When the force or power is between the weight and the fulcrum, the lever is of the **third order.**

The order of the letters F, W, P indicates the middle position in order of the three kinds of levers.

In all kinds of levers, however, the rules and statements previously given about the lever hold good. Now, the bones often act as levers, an attached muscle or muscles supplying the power or force to move them, while the resistance is the weight of the limb acted upon, and anything with it. In the movement produced the point of insertion and all attached to it is made to come nearer the origin, which remains fixed. The third kind of lever, with the power nearer the fulcrum than to the weight, so that there is a great gain of speed by a power greater than the resistance, is the most common in the body; for rapidity of motion is often required, and is more useful to an animal in the struggles of life than slow heavy weight.

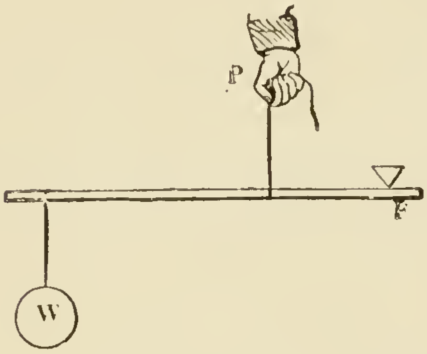


FIG. 138.—Lever of third order (power in the middle). (From Tate's "Mechanism.")

86. Examples of Muscular Action.—Let us first consider the bending or flexion of the forearm. This is effected by the power supplied by the contracting biceps muscle. The biceps muscle is a large muscle lying in front of the humerus, and having its fixed point, or origin, on the scapula, to which it is attached by means of two tendons (Fig. 139). It is inserted on the radius by a single tendon at about an inch and a half from the head of this bone. Between the origin and insertion lies the belly of the muscle, free from attachment to bone. When the biceps contracts, *i.e.* shortens and increases in girth, it pulls up the radius and with it the ulna and the hand, the ulna turning as on a hinge at the elbow articulation. Here the elbow-joint is the fulcrum; the power is the force supplied by the contracting muscle, and acts at a short distance below the head of the radius; while the resistance to be moved is the weight of the hand and what it contains. The thickening and hardening of the biceps as it contracts may be readily felt and seen by the reader as the forearm is drawn up. This is

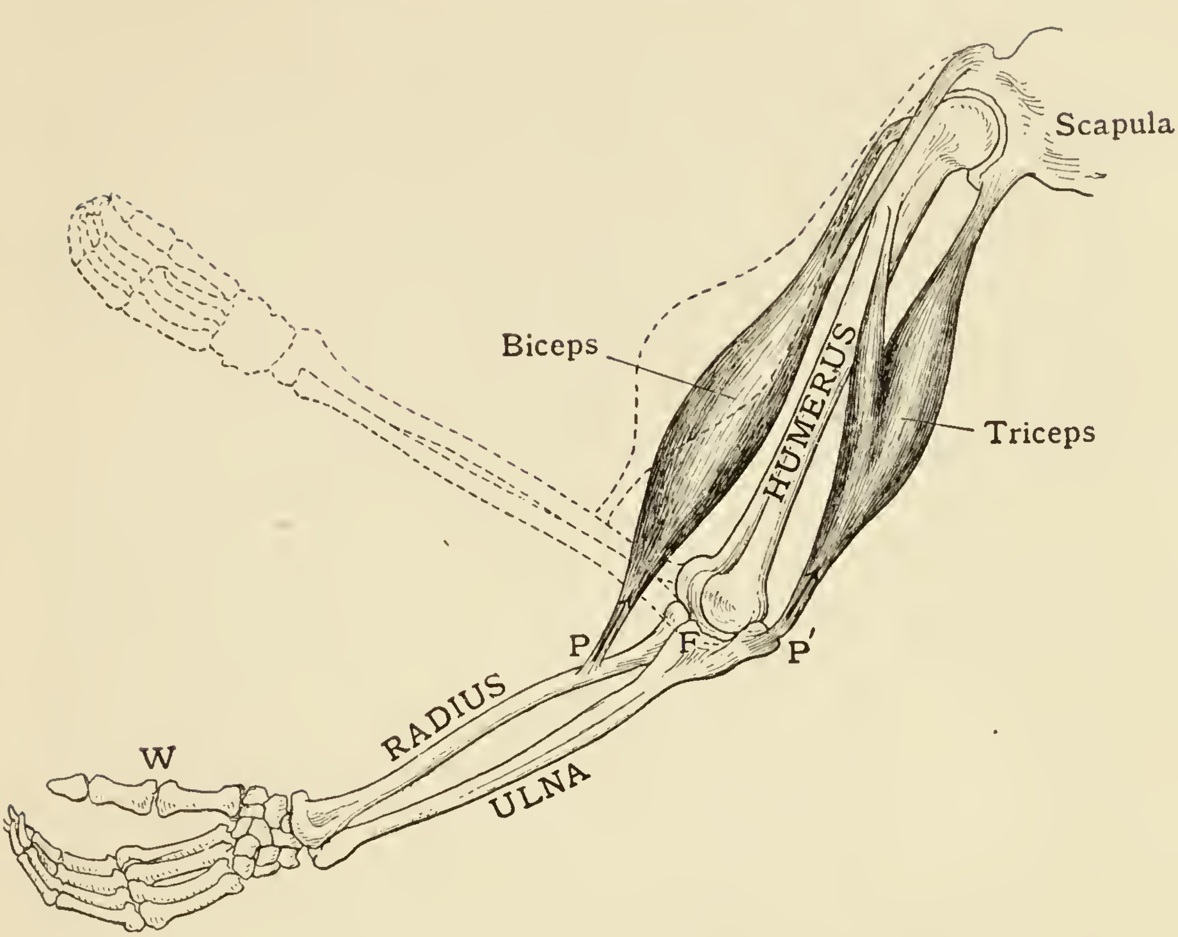


Fig. 139.—Illustrating the action of the biceps muscle in raising the hand, and the antagonistic action of the triceps muscle. P and P′, insertion of muscles where the power acts; F, fulcrum; W, weight, or resistance.

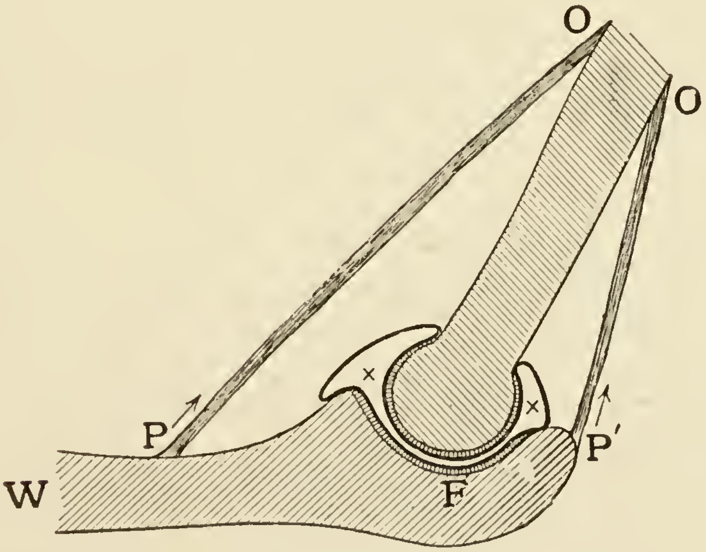


Fig. 140.—Diagram to illustrate the structure and action of the hinge-joint at the elbow. The ends of the humerus and ulna are covered with articular cartilage, shown by fine lines in the figure. Over the articular cartilage, and reflected from humerus to ulna, is the synovial membrane indicated by a black line, × ×, lying in the synovial bag. Ligaments fasten one bone to the other, but these are not shown in the figure. OP represents the biceps muscle inserted at P, and flexing the arm. OP′ represents the triceps muscle extending or straightening the arm, and acting at P′. F is the fulcrum.

evidently an example of a lever of the third order, for the power acts between the fulcrum and the weight. It is also clear that a small movement of the biceps acting at P will cause a considerable movement of the hand in the same time. A large range of movement is obtained by a small amount of muscular contraction, and to effect this advantage the pull of the muscle at its insertion on the radius must be many times greater than the weight to be raised.

Consider now the straightening or extension of the forearm. This is effected by a muscle called the triceps muscle, lying at the back of the arm, and the action of which opposes that of the biceps. Its origin is partly a tendon attached to the scapula, and partly two attachments at the upper end of the humerus. Its insertion is where the tendon at its lower end is attached to the upper end of the ulna, a little behind and above the fulcrum at the elbow-joint. When the triceps muscle contracts and exerts its power at the upper end of the ulna, it pulls the end of the ulna upwards, and, in so doing, straightens the flexed arm. In this arrangement the ulna is acting as a lever of the first order, for the fulcrum, though close to the power, is between the power acting at the upper end of the ulna and the resistance of the weight of the hand (study Figs. 139 and 140).

The biceps muscle and the triceps are evidently so arranged as to oppose each other in action. Each furnishes an example of two classes of muscles, called, from the result of their action, **flexors** and **extensors**. *Flexors are muscles which, by their contraction, bend or draw up a limb or part of a limb; extensors are muscles which, by their contraction, straighten a flexed part of the body.* Just as the forearm is flexed by the biceps and extended by the triceps, so each finger has its flexor and extensor muscles.

The bending or flexing of the leg at the knee-joint is effected by muscles at the back of the thigh, especially by the biceps of the leg (**biceps femoris**), which has a double origin on the hip-bone and on the femur. Its lower tendon is inserted below the knee-joint on the back of the fibula, and here the power acts. The knee-joint above is the fulcrum, and the resistance is the weight of the leg and foot acting at the centre of gravity a little above the ankle (lever of the third order). The extensor muscles that straighten the leg when thus bent (the **rectus femoris, vastus extensus**, and **vastus internus**) lie in front of the thigh, the most important being the one that is inserted both on the patella and below the knee on the front of the tibia.

The head, as it nods backwards and forwards upon the fulcrum of the topmost vertebra, or atlas, is a lever of the first class, and resembles a see-saw, in which the power and weight are first at one end and then at the other. In nodding backwards, muscles springing from the back of the neck and inserted on the back of the head furnish the power, and the resistance is the weight of the skull and face in front of the fulcrum. In nodding forwards, the weight to be moved is at the back of the head, and the power is furnished by muscles in front, inserted beneath the chin. It should be noted, however, that the centre of gravity of the head lies a little in front of the fulcrum, or pivot of support on the atlas, so that the action of the muscles inserted on the back of the head is needed to keep the head upright. When the contraction of these muscles ceases, as in sleep, the head, if not otherwise supported, nods or falls forward.

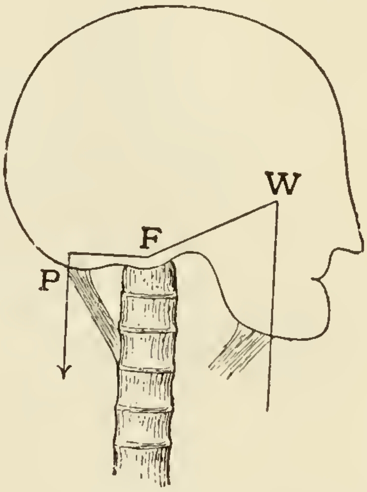


Fig. 141.—Head rocking on the atlas. Lever of the first order.

There are few examples of levers of the second kind in the body. The best is furnished by a movement at the ankle-joint, when the body is being raised to rest on the toes. Here the power is furnished by the great **gastrocnemius muscle**, which forms the calf of the leg, and which has its origin partly on the femur and partly on the upper end of the tibia and the fibula. It is inserted on the heel-bone by a long and strong tendon termed the **tendon of Achilles**, and it is on this bone that the power furnished by the contraction of the muscle acts. When the body is resting on the toes, the fulcrum is at the toes, and the weight of the body is acting at the ankle-joint between the fulcrum and the power acting at the heel.

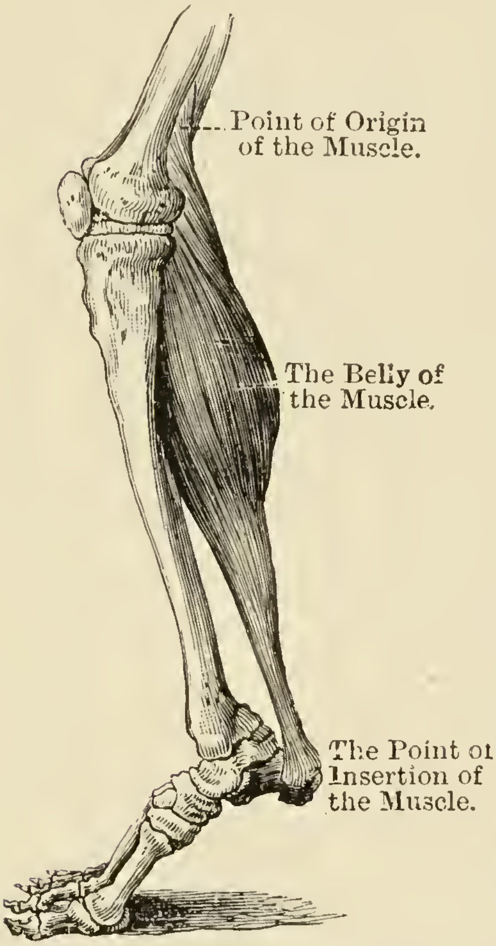

Point of Origin of the Muscle.
The Belly of the Muscle.
The Point of Insertion of the Muscle.

FIG. 142.—Gastrocnemius muscle raising the body on the toes.

In **standing**, two sets of opposing muscles are in harmonious action, one set in front tending to pull the body forwards, and another set behind tending to pull the body backwards. Thus the extensor muscles on the front of the thigh and lower leg are balanced by the flexor on the back of the thigh and in the calf.

In **walking**, the weight of the body is thrown alternately on the one limb and on the other. Just when the advanced foot has reached the ground, the muscles of the calf in the hinder foot contract, and, raising the body on the toes, push it forwards. This causes the leg behind to swing in front, and it then becomes the advanced basis of support, the other foot being then raised on the toes, and so on.

It is thus clear that motion and locomotion are alike due to muscular action, and dependent on the mechanical relations that exist between muscle, bones, and joints. Most movements are due to the action of several muscles or groups of muscles acting in co-ordination. In the case of the skeletal muscles—those which cover the bones and form the figure—the muscle is usually put into action by an effort of the will, the impulse travelling along a motor nerve to the muscle from some part of the central nervous system. The power which the muscles use to execute the work they perform is derived from the oxidation of the food and of their own substance, as will be better understood later.

87. Some Important Muscles.—As already mentioned, there are nearly three hundred muscles in the body. They are of various sizes, kinds, and shapes, so as to be suited for their particular work. Some are seen at the surface, but others are more deeply seated. Fig. 143 shows the superficial muscles and tendons of the palm of the hand. The long tendons are mostly tendons of muscles that arise on the bones of the forearm, and that serve as flexors of the fingers, the extensors being at the back of the arm and hand. The small muscles forming the ball of the thumb enable it to be *abducted* or moved outwards, *adducted* or moved inwards, and also placed *opposite* and against the fingers. The face muscles arise from bones of the face, and are inserted on them, or in some cases on the skin of the face. Their contraction produces the various kinds of facial expression, and the movements of speech and mastication.

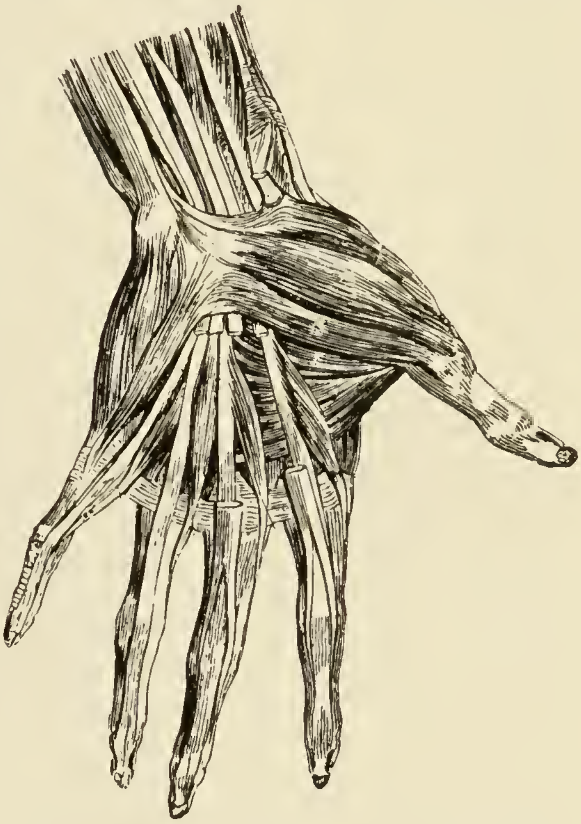


Fig. 143.—Muscles and tendons of the palm of the hand. (From Quain's "Anatomy.")

In addition to the muscles already mentioned, we can only find space to mention a few more important ones. Thin flat muscles exist beneath the skin of the scalp, attached to the cranium, and by their action move the scalp backwards and forwards, raise the eyebrows, and wrinkle the forehead. The expression of the face is due to flat muscles arising from one or other of the face-bones and inserted on the skin of the face. Mastication, or chewing, is effected by an up-and-down motion of the lower jaw, together with some lateral and a slight to-and-fro motion. These movements are brought about by the action of several muscles, the chief of which are the masseter, frontal, and pterygoid muscles. The masseter muscles form part of the cheek, and, arising on the superior maxilla, pass downwards and backwards, to be inserted on the outer surface of the lower jaw. Place the finger just in front of the external opening of the ear, and notice, as the lower jaw falls, the movement of its condyle at the articulation of this condyle with the temporal bone (par. 79). Now place the fingers on the angle of the jaw, and note the movement of this muscle as it contracts as the mouth is forcibly closed.

In the trunk we may notice on each side of the front of the chest a great fan-shaped muscle called the **pectoralis major** (Fig. 134), which serves to move the arm inwards, and depress it when elevated. Its action is opposed by a triangular muscle at the back of the neck and over the shoulder-blade, called the **trapezius**. In front we may also notice the thin abdominal muscles that assist in forming the walls of the abdomen, and compressing the viscera. In the arm, besides the biceps and triceps already mentioned, we may note a thick muscle covering the shoulder, and called, from its resemblance to the Greek letter *delta* (Δ), the **deltoid** muscle. In the lower arm the muscles with long tendons, that serve to bend and straighten the fingers, are the flexors and extensors of the hand.

In the leg, besides those already mentioned, we may notice the long thin muscle running across the front of the thigh, called the **sartorius** (Lat. *sartor*, "a tailor"), as it is used in crossing the legs; and the great muscles at the back of the thigh, which bend the knee, and the tendons of which can be felt in the bend of the joint as "hamstrings."

88. The Nervous System.—As just stated, the biceps and other muscles are often contracted as the result of an

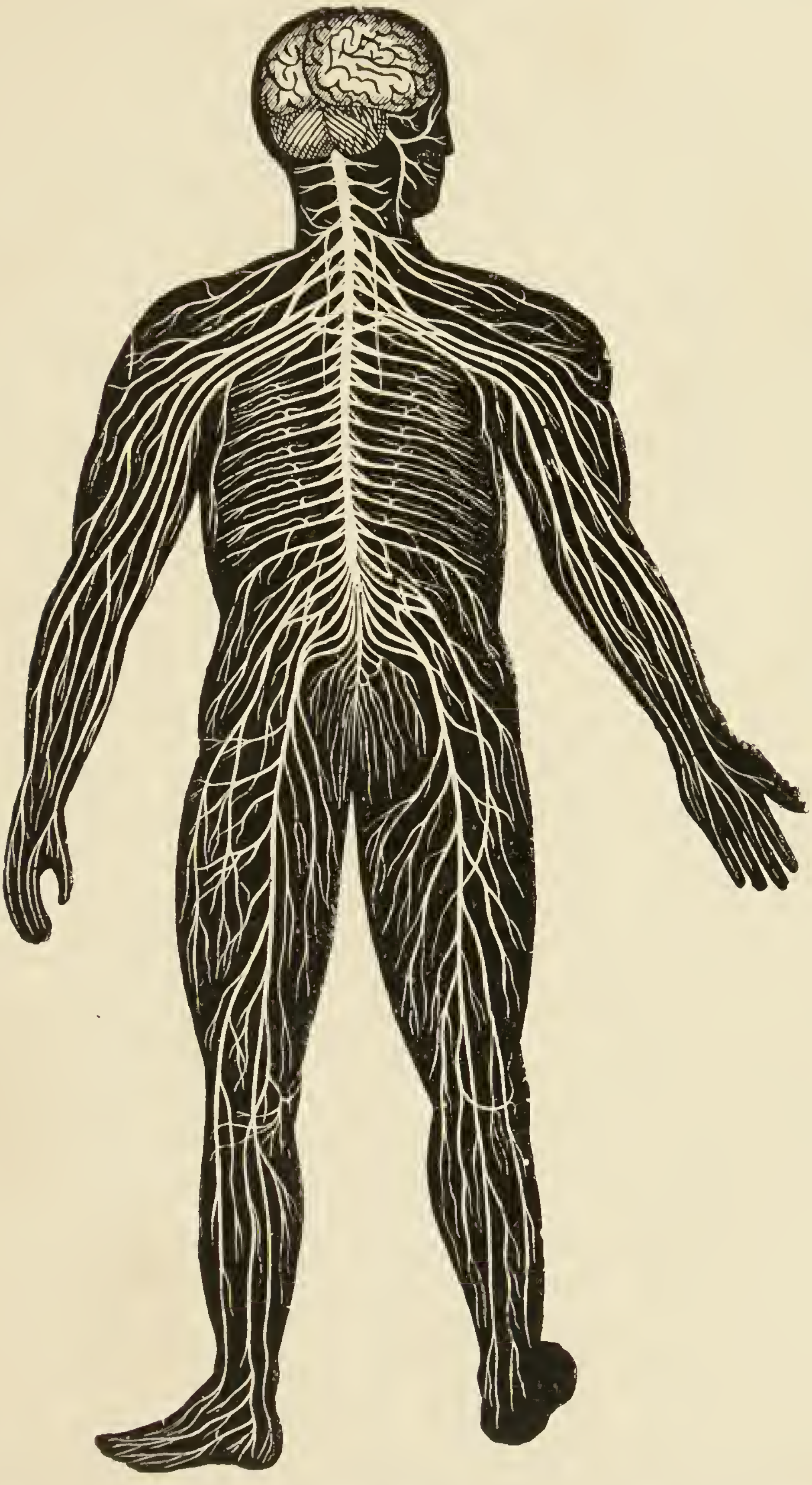


FIG. 144.—The brain and spinal marrow, with the nerves connected with them distributed to all parts of the body. (From Furneaux's "Elementary Physiology.")

effort of the **will.** Now, the will is a kind of mental activity that has its seat in the brain, and the brain is a portion of the regulating and controlling mechanism of the body, which is known as the nervous system. The chief portion of the nervous system is termed the **cerebro-spinal system,** and consists of the brain and spinal cord, and all the nerves given off from the brain and spinal cord to the voluntary muscles and the organs of special sense (eyes, ears, tongue, nose, skin). The brain occupies the cavity of the cranium, and consists of soft grey and white nerve-matter, arranged in definite folds and forms. The spinal cord is a long cylinder of nerve matter lying in the spinal canal of the vertebral column. From both the brain and the spinal cord pass numerous **nerves** in the form of fine white cords or fibres, and these break up into finer and finer branches that pass to all parts. Those from the brain pass through small holes at the base of the cranium to the sense organs of the head and to the face chiefly, and those from the spinal cord pass out between the vertebræ to the muscles of the trunk and limbs and to the skin.

The brain and the spinal column form a central system, and the nerves connected with them are of two kinds: (1) nerves carrying impulses **to** the central system from the skin, or from one of the sense-organs, and known as **afferent** (Lat. *af*, "to;" *fero*, "I carry") or **sensory nerves**; (2) nerves carrying impulses from the central to the various muscles and other organs, and known as **efferent** (Lat. *ef*, "out of;" *fero*, "I carry") **nerves.** The second kind are also known, when the impulse leads to muscular contraction, as **motor nerves.** Some efferent nerves, however, pass to glands, and lead to secretion only.

As an example of the action of the nervous system, consider what happens when a cat sees a mouse. Here a stimulus or excitation reaches the eye, and a sensory nervous impulse travels inwards to the brain, from which outgoing or motor impulses are sent to certain muscles that lead to purposeful movements with the object of capturing the mouse.

We are not always conscious of the outgoing nervous impulses that set our muscles in motion. If a hand be suddenly and rapidly brought towards the eye, a sensory impulse passes to the brain, and the eyelid instantly closes in obedience to an unconscious motor impulse. Movements produced by the action of the brain or spinal cord without the action of the will, and in consequence of sensory impulse, are said to be due to **reflex action.** Many such involuntary movements due to reflex action are constantly taking place.

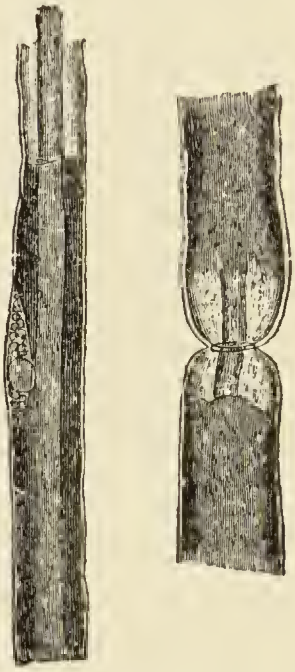


Fig. 145.—Two portions of the nerve-fibres (highly magnified), showing the axis-cylinder and the surrounding sheath. (From Quain's "Anatomy.")

Nervous Tissue consists of nerve-cells and nerve-fibres. The grey nervous matter is found in certain parts of the brain and spinal cord, and consists for the most part of minute nucleated cells with many processes, one of which passes into a nerve-fibre (Fig. 2, E). The white nervous matter consists of very fine fibres. An ordinary nerve, which appears as a fine white thread, consists of a bundle of such fibres bound together by fine connective tissue. An individual nerve-fibre is only about $\frac{1}{2000}$ inch in diameter. It consists, however, of a central conducting axis-cylinder surrounded by two sheaths.

CHAPTER XVI.

STRUCTURE OF A COMMON QUADRUPED, AS EXEMPLIFIED BY THE CAT.

89. General Remarks.—The body of any common quadruped, such as the cat, dog, rabbit, or cow, is formed on the same fundamental plan as that of man, already described; and the functions of the various organs are very similar to those of the human body, for the normal horizontal position of the body of a quadruped, compared with the normal upright position of man, does not indicate much structural difference. Beneath the hairy skin of such a quadruped lies the flesh or muscles surrounding the bones, while the trunk is divided into a thoracic and abdominal cavity by a thin musculo-tendinous partition that arches forwards (in man upwards), and is called the **diaphragm.** Within the bony thorax thus formed there lies, as in man, the heart with its great blood-vessels, and the lungs with the trachea leading into them from the mouth and nasal cavities. Both heart and lungs are similar in structure and mode of action in man and the cat. Within the abdomen, close to the diaphragm, lies the stomach, which is an expanded portion of the gullet, that begins at the back of the mouth, and which is continued in coils of intestines to the exit or anus—gullet, stomach, and intestines forming the alimentary canal. The liver, too, lies in lobes below the diaphragm. The abdomen also contains the pancreas, the spleen, the two kidneys, and the urinary bladder (see Fig. 146).

The nervous system, as in man, consists of two great connected centres, the brain and the spinal cord, the former lying in the cavity of the cranium, and the latter lying in the spinal canal of the vertebral column. Nerves proceed from these centres to all parts of the body, the nerves of motion (motor nerves) conducting from the centre outwards, and the nerves of sense (sensory nerves) conducting from without inwards to the brain or spinal cord.

Further, the daily life of such a quadruped as the cat resembles our own in many respects. It moves spontaneously and reacts to external stimulation, takes from time to time nourishment by feeding and drinking, digests, excretes waste products, respires regularly as seen by the alternate rising and falling of the chest, and propagates its own kind.

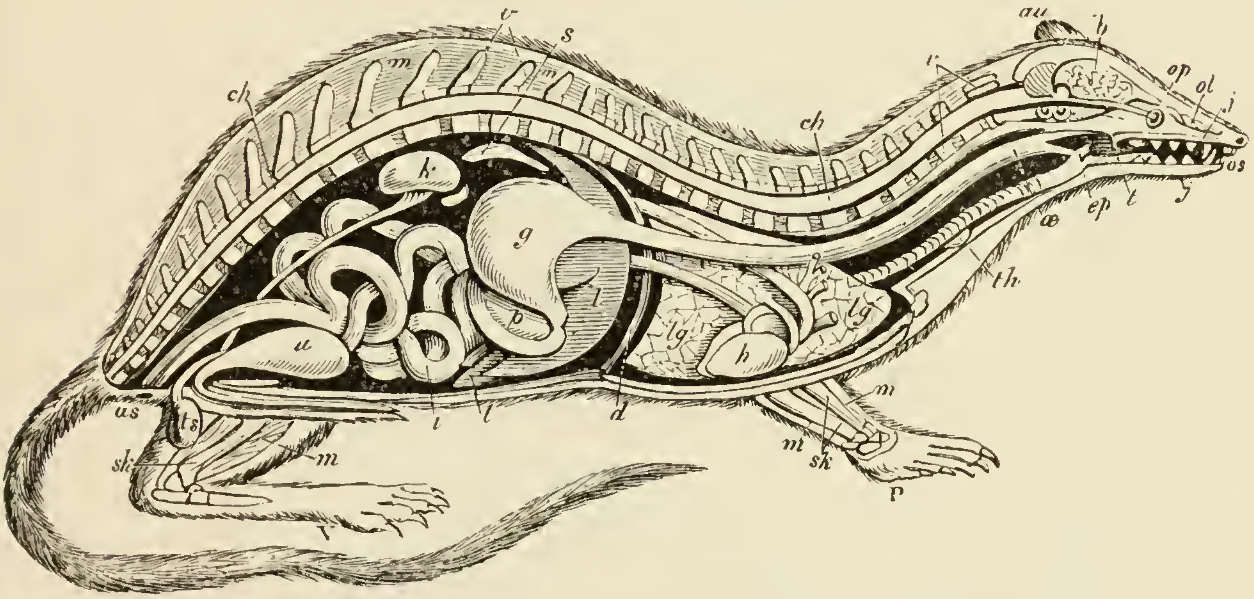


FIG. 146.—Longitudinal section through the body of a mammal (diagrammatic). *os*, mouth ; *j*, *j*, jaws ; *ol*, olfactory nerve ; *op*, optic nerve ; *b*, brain ; *au*, external ear ; *t*, tongue ; *ep*, epiglottis ; *œ*, œsophagus ; *th*, trachea ; *v*, vertebral processes ; *ch*, spinal cord ; *lg*, lung ; *h*, heart ; *m*, muscle ; *s k*, bones of leg ; P, foot ; *d*, diaphragm ; *l*, liver ; *g*, stomach ; *s*, spleen ; *p*, pancreas ; *i*, intestine ; *k*, kidney ; *u*, bladder ; *as*, anus ; V, hind foot. (From Owen's "Comparative Anatomy.")

An important matter in all mammals is the character of the *teeth*, for these are largely determined by the nature of the food, and this, in its turn, indicates to a large extent the habits and structure of an animal. In man the four different kinds of teeth are nearly similar in size, and adapted to a mixed diet (par. 79). In a carnivorous animal, like the cat, the canine teeth are largely developed, and some of the others specially adapted for cutting flesh, as we shall shortly see. In gnawing animals (rodents), like the rabbit, the incisors are the teeth specially developed. Other points of special importance, where differences are found, are the structure of the *foot* and the action of the fore limbs, and these will be duly noted below for the animal we are now specially considering.

90. The Skeleton of the Cat.—On examining the skeleton of the cat, we are at once struck with its general correspondence to that of man, although the natural position of the body in man is an erect one, and in a quadruped a horizontal one. There should be little difficulty in naming most of the bones from those of the human skeleton, although the form and relation to one another are somewhat different, and the number of bones somewhat greater.

In man the skull is balanced on the vertebral column, but in the cat and other quadrupeds it is attached or suspended, as it were, from the extremity of the column. To aid in keeping it in position there is a strong elastic ligament, but little developed in man, called the **ligamentum nuchæ,** which runs from the spinous processes of the upper vertebræ to a protuberance on the occipital bone at the back of the head. The vertebral column, too, is prolonged by the addition of a number of small vertebræ, which form the bony part of the movable tail. (The four bones of the os coccygis in man are rudimentary tail vertebræ.)

The cat, indeed, is not able to stand upright, for its hind legs can never be completely straightened into the same line as the backbone, and the articulation at the shoulder does not allow the fore limbs to be lifted up towards the head nor dropped down by the sides. The proportions of the limbs, too, are of such a nature that both the elbow and the knee are placed close to the trunk, as may be seen from the figure, or by passing the hands up the cat's limbs.

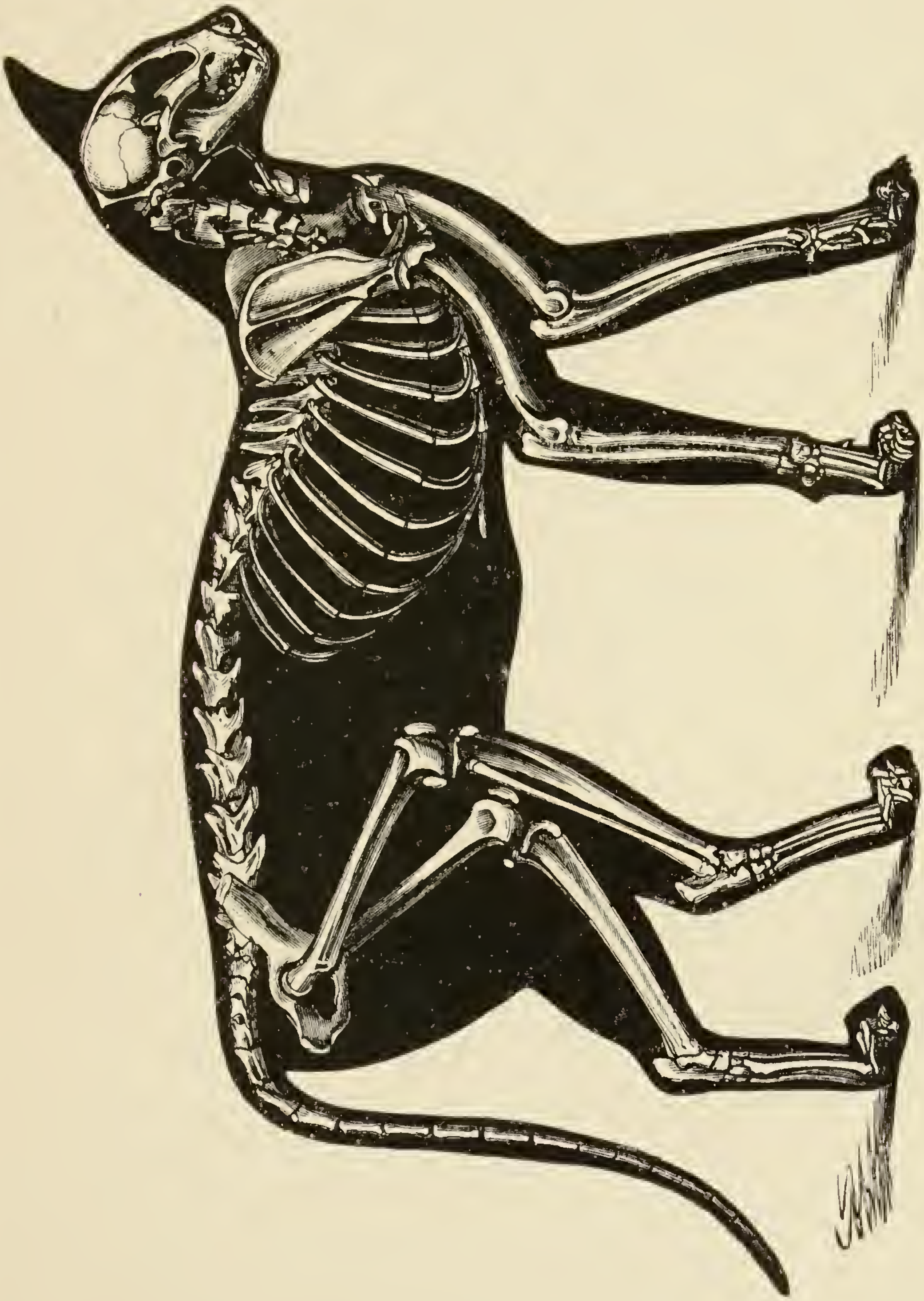


Fig. 147.—Skeleton of a cat, with outline of the body. (From St. George Mivart's "The Cat.")

What looks like a knee turned backwards on a hind limb is really the heel at the beginning of a long foot.

To aid in identifying the bones corresponding to those of the human skeleton, we add a figure of the left side of the skeleton with the names attached to the chief bones.

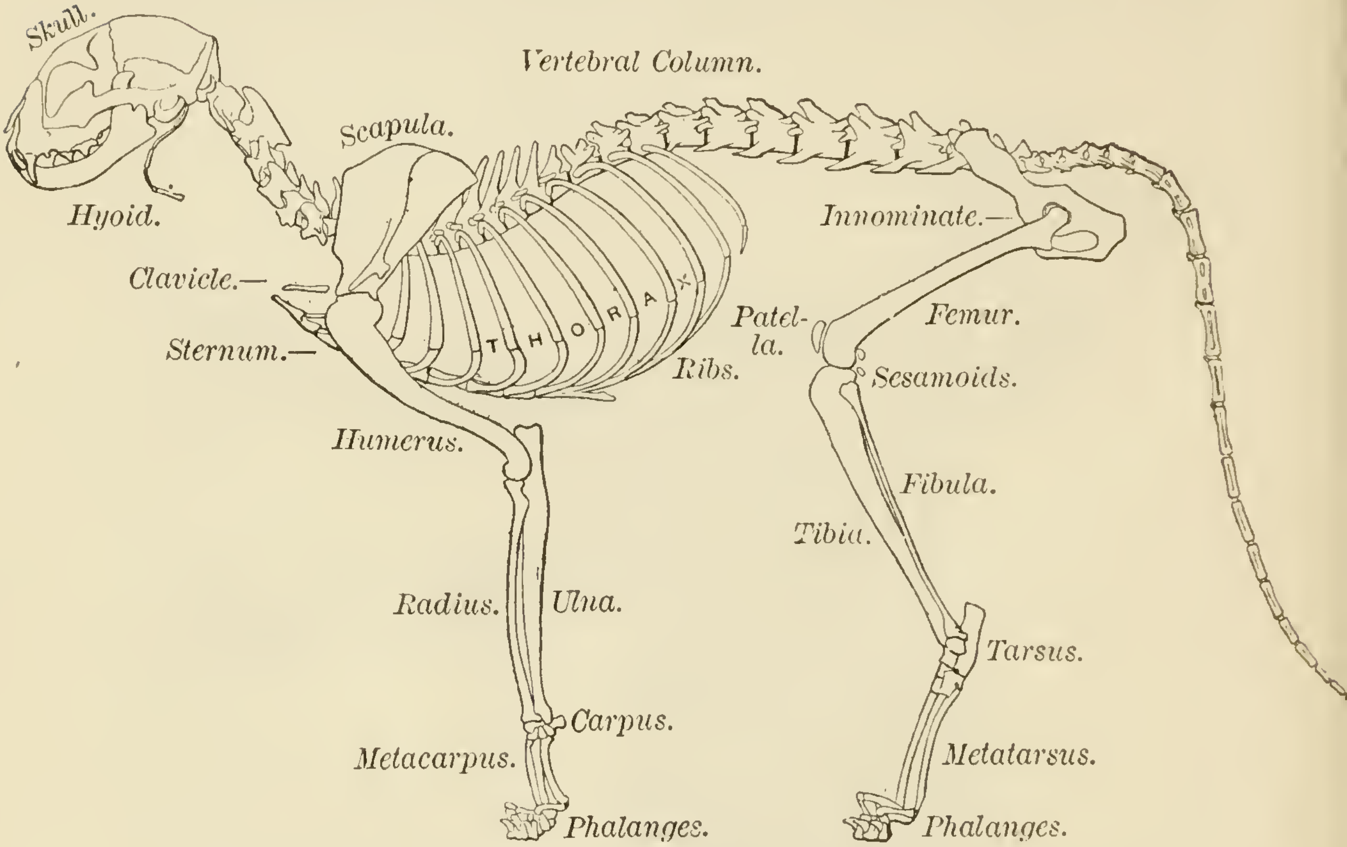


FIG. 148.—The skeleton of the cat, left side only. (From Prof. Jayne's "Mammalian Anatomy.")

The student should, if possible, use the figures with the cat's skeleton before him. It may be met with in many museums or purchased from a dealer in such objects.

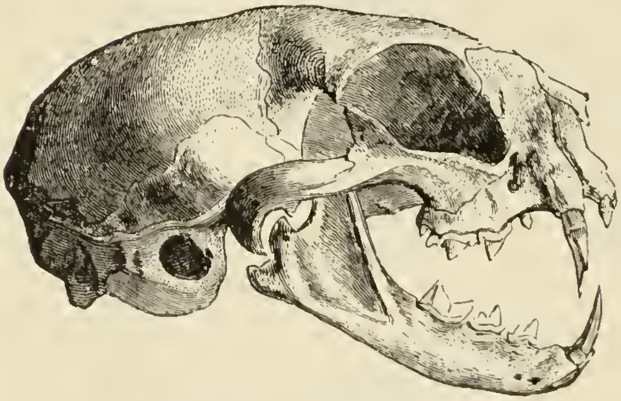


FIG. 149.—Skull of cat (side view). (From Schmeil's "Zoology.")

A few points of special interest in the skeleton of the cat may now be noted. The skull, which is articulated by two condyles with the first vertebra, is longer than in man, and the face portion is largely developed. The long lower jaw, or mandible, forms a joint with the other part of the skull below the ear, and the articulation is such as to allow only of an up-and-down motion of the jaws, and not of any sideways or backward-and-forward movement, as is the case with animals that grind their food. There is no distinct chin.

The teeth of the cat differ greatly from those of man, and are well adapted to its carnivorous mode of life. In the adult cat there are *sixteen* teeth in the upper jaw and *fourteen* teeth in the lower, the two sides of each jaw being alike. In a side half of the upper jaw we have at the front three simple incisor teeth, the outermost incisor being the largest. With the three incisors in the other side of the jaw we get a row of six such teeth in front (Fig. 150). Near to the outermost incisor, but at some distance, in each half of the upper jaw is a large conical tooth called the **canine** tooth, which has a long thick fang. Then come three premolar teeth, the third of which is large, and provided with cusps and sharp edges. This tooth is known as the upper **sectorial** or **carnassial** tooth. Behind this third premolar is a fourth tooth in each half of the upper jaw, a small molar with a grinding surface.

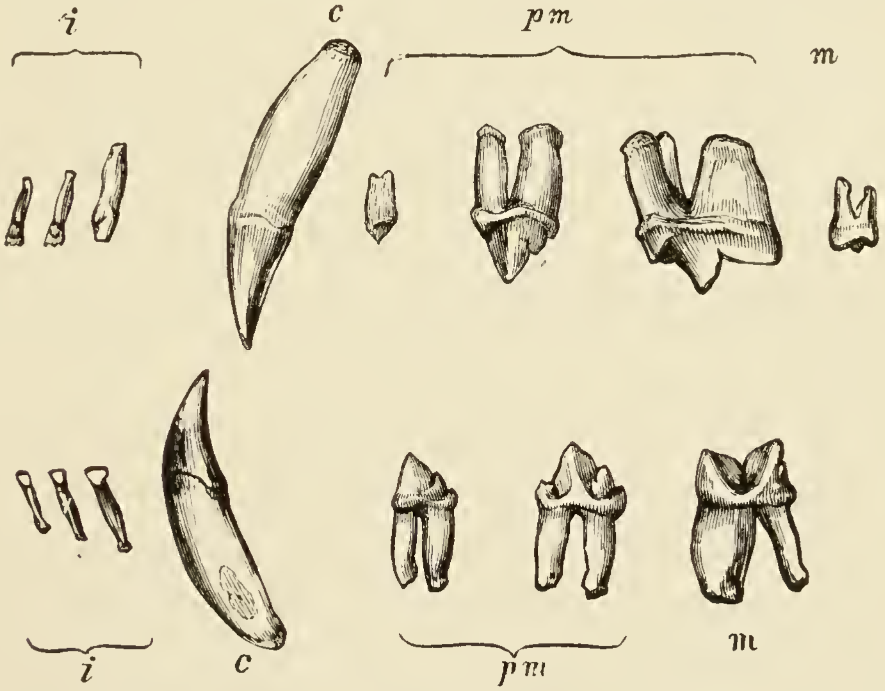


FIG. 150.—Teeth of one side of each jaw of the cat. (From St. George Mivart's "The Cat.")

In the lower jaw there is on each side, starting from the middle line in front, three incisors, and then comes, without any interspace, a large pointed canine, so placed as to bite just in front of the upper canine when the jaws are closed (Figs. 150 and 156). Then follow two premolars, and after these the lower molar called the lower **sectorial** tooth. It is much larger than the small upper molar, and has a notched crown and sharp edges like the upper sectorial. The trenchant margins of the last premolar of the upper jaw and the molar of the lower jaw, and of the upper and lower sectorial teeth, work together like the blades of scissors.

The dental formula (par. 79) of the cat is therefore—

$$I\,\frac{3-3}{3-3},\ C\,\frac{1-1}{1-1},\ Pm\,\frac{3-3}{2-2},\ M\,\frac{1-1}{1-1} = 30.$$

The bones called **clavicles** should be noticed in the cat. They are quite different from those in man, being merely slender bones embedded in muscle between the point of the shoulder and the sternum without any articulation or proper ligaments of connection (compare Figs. 121 and 148).

Another point of importance in the skeleton of the cat is that the limbs are so constructed that the animal walks on its toes—that is, on the phalanges, so that the metacarpal and metatarsal bones are nearly vertical, and the wrist and heel at some distance from the ground. In man the tread is on the whole foot, and the heel comes to the ground. This is also the case with both fore limbs and hind limbs in monkeys and bears. In the cat, as is clearly seen in the figure showing the fore limb, which corresponds to the human arm, we see that below the humerus, which articulates with the radius and ulna at the knee high up, the wrist-bones and the metacarpal bones are all in a nearly vertical position, as the animal stands on its toes. The five toes on each fore foot are provided with strong curved claws on the last toe-joint.[1] These claws, when not in use are raised or retracted into sheaths by the action of strong elastic ligaments. The claws are thus saved from unnecessary blunting. (Compare with dog, whose claws cannot be retracted, and are always blunt.) When the cat is roused, two flexor muscles, the tendons of which are attached to the under side of the last joints, pull down these joints and the claws on them with great rapidity.

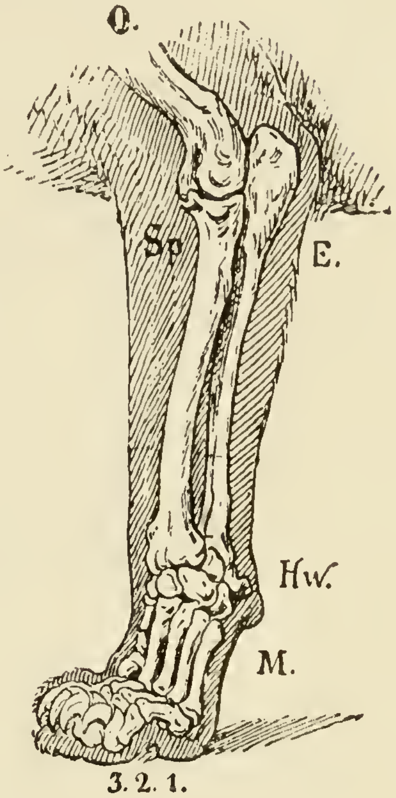


Fig. 151.—Fore leg (arm) of cat. O, humerus; Sp, radius; E, ulna; Hw, wrist, or carpal bones; M, metacarpals; 1 2 3, phalanges of toes. (From Schmeil's "Zoology.")

The long hind legs of the cat have also bones corresponding to those of the human skeleton, but they are longer than the fore legs, and the knee is bent far forward high up and close under the body. The long hind foot causes the *heel* to be raised very high when the animal is standing and walking. The heel must not be mistaken for the knee, as is sometimes done. Four toes with retractile claws are found on each hind foot. When pussy "sits," she has then the whole of the hind feet from the heel downwards upon the ground.

One or two minor points of the skeleton of no special importance may now be mentioned. The hyoid bones at the base of the tongue, with processes attached to the temporal bones of the skull and others attached to the larynx at the top of the windpipe, are more developed than in man. There are also in the cat several small independent bones called **sesamoid** bones, occurring in muscular tendons or joints. The largest and most important sesamoid bone in the human body is the patella, or knee-cap.

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[1] Claws differ from nails only in the fact that they grow on all sides of a terminal point of a finger or toe instead of on one side only. The bone of the terminal joint forms the core of the claw.

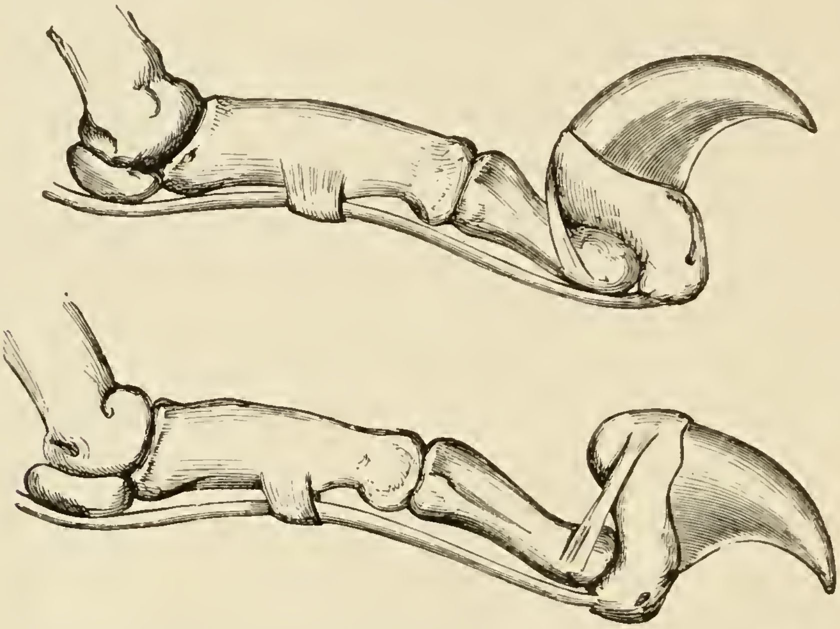

FIG. 152.—The phalanges of one toe, showing above the claw retracted and below the claw drawn out by the action of the tendon beneath. (From St. George Mivart's "The Cat.")

91. The Cat Family.—The highest class of vertebrate animals is termed **Mammalia** (Lat. *mamma*, "a teat") (par. 5), as the females all suckle their young. The mammalia include a number of divisions or orders, one of which is called **Carnivora** (Lat. *carno*, *carnis*, "flesh"; *voro*, "I devour"). The carnivora are flesh-eating, predatory mammals divided into a number of separate families. One of these families is the dog family, and includes the dog and the wolf. Another of these families is termed **felidæ** (Lat. *felis*, "a cat"), or the cat family. It includes the lion, tiger, leopard, lynx, and domestic cat. All the members of the cat family have a hairy skin, and the clavicles are rudimentary or absent. They are all digitigrade (Lat. *digitus*, "a finger or toe"), *i.e.* walk on the toes, and while the fore feet have five toes, the hind feet have only four. The last joint of all the toes is furnished with sharp retractile claws, and all the cat family are exceedingly light on their feet. The facial part of the skull is shorter than in other carnivora, as the dog family, and all possess powerful muscles of mastication. The teeth are always of three kinds—incisors, canines, and molars, the canines being long and pointed, and some of the molars provided with cutting or trenchant edges. The tongue is roughened and rendered prickly by horny papillæ, and the iris being very movable, the pupil of the eye can be contracted into a vertical line in a strong light. Lastly, the stomach in the cat family is comparatively short, and the intestines comparatively simple in accordance with the easily digested character of animal food.

The bodies of animals belonging to the cat tribe are covered with fine, short, smooth hair, known as *fur*. It really consists of two parts, the short, close, silky hair next to the skin, which is the real fur, and some longer and stronger hairs standing out above the real fur, and much more thinly spread. These longer and stronger hairs are termed the *over-hair*.

92. The Structure and Faculties of the Cat adapted to a Predatory Life.[1]—By the acuteness of its senses, the form and structure of its body, and its mental faculties, the cat is admirably fitted for the rapid movements required in plundering and preying on small animals as well as for escaping and defending itself from enemies.

(*a*) **The Acuteness of the Cat's Senses.**—The cat is possessed of an extremely **fine sense of hearing**. The slightest noise, as of a moving mouse, appears to wake it, and by the use of the movable muscles of the short, pointed ears it is able to judge of the position and distance of the moving object. The cat is also **quick-sighted**, having large and brilliant eyes. As a protection against too bright a light, the cat is able to contract the pupils of the eyes until they form only a narrow vertical slit. (The pupil is the hole or opening in the iris, the circular curtain of the eye, through which the light passes; it appears as a black spot in the middle of the coloured iris owing to the darkness at the back of the eye.) In the bright daylight, therefore, the pupil appears as a narrow slit; but as it grows dark, the light rays become fewer and fewer, and the pupil dilates more and more to take in the fewer rays. When quite dusk, the pupil becomes nearly circular. A cat, however, cannot see in perfect darkness. (The human pupil varies in size with the amount of light, but only within small limits.) The shining of a cat's eyes in the dark (not in perfect darkness) is caused by the reflection of the few rays entering the eye from a bright-coloured membrane called the *tapetum* at the back of the eye.

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[1] This paragraph is adapted in part from the account of the cat given in Dr. Otto Schmeil's "Lehrbuch der Zoologie."

Another acute sense possessed by the cat is the **sense of touch.** This sense has its seat in the skin, especially the skin of the paws, tongue, and that connected with the whiskers, as the vibrissæ or long hairs of the upper lip are called. The skin at the roots of these hairs, as well as at the roots of the long hairs over the eyes, is extremely sensitive, and the slightest touch of these hairs is instantly felt. The whiskers of the common cat are just as wide as her body, and, being so sensitive, enable her to judge at once when hunting her prey whether the body can pass through any opening without noise. The sense of smell in many cats is somewhat dull, but it is easy to see how helpful the other acute senses are in enabling the animal to become aware of the prey on which it lives.

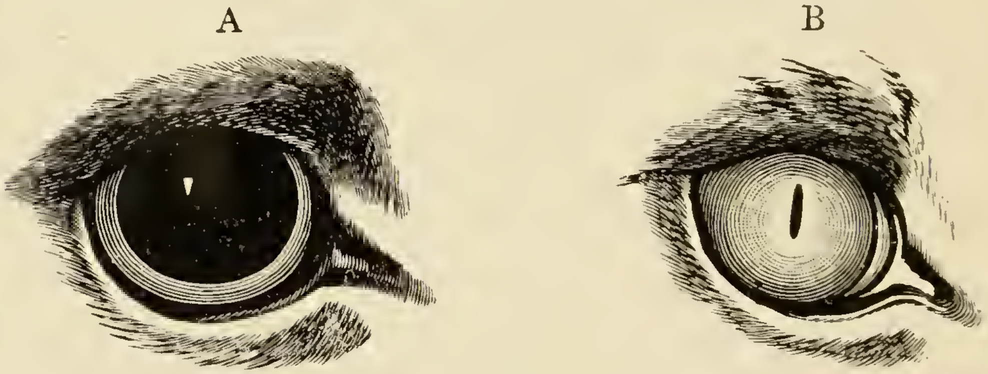

FIG. 153.—A, cat's eye at night, with large circular pupil; B, cat's eye by day, with pupil a mere slit.

(*b*) **The Form and Structure of the Cat's Body adapted to Rapid Movement and the Capture of Prey.**—The long conical form of the cat's body is well adapted for rapid movement, as the resistance of the air is thus reduced to the smallest, while its general structure leads to marvellous agility in all its movements. It can move **with great silence**, since it not only walks on its toes, but beneath these, and at the end of the metacarpal and metatarsal bones, are soft fleshy balls, or pads, covered with thick skin and short hairs, that render them as soft and noiseless as velvet (Figs. 154 and 155). The cat can, therefore, approach its prey stealthily without being observed, and it then springs upon it by sudden leaps. It also flees in a succession of leaps from an enemy, its body being well adapted for such leaps by its bent legs, the sudden straightening of which by strong muscles sends it forward. The absence of true clavicles—as the rudimentary ones do not touch either the scapula or the sternum, and the consequent mobility of the shoulder-blades (try how easily, on the living animal the shoulder-blades can be moved)—enable the cat to alight on its fore legs without jar or injury. In man, with his specially active and mobile arms, a collar-bone, or clavicle united with the shoulder, is needed; but this firm connection produces a great shock when falling on the hands, and often leads to fracture of the collar-bone. The absence of true clavicles also enables the cat to squeeze itself through a hole which is just large enough to allow its head to pass through.

The great flexibility and elasticity of the jointed vertebræ forming the backbone of the cat enable it to twist and turn its body to a great extent, so that by skilful contortion of the body, aided by a rudder-like use of the tail, the cat is able, on falling, to bring the feet round towards the ground, first the fore feet and then the hind feet, so that she always manages to drop on her feet. If let fall back downwards, with only a foot of space below, a cat alights on the feet. This peculiar flexibility of her body, together with the flexible joints of her legs, is of service to the cat in another way. When seized by an enemy, of which the dog is chief, she can turn round either the fore part or hind part of her body so as to bring her claws into use.

The sharp curved claws found on the last bones of the toes, the protection and action of which have already been explained (par. 90), not only enable the cat to seize and wound its victims, but enable it to climb trees and walls in pursuit of birds or in an endeavour

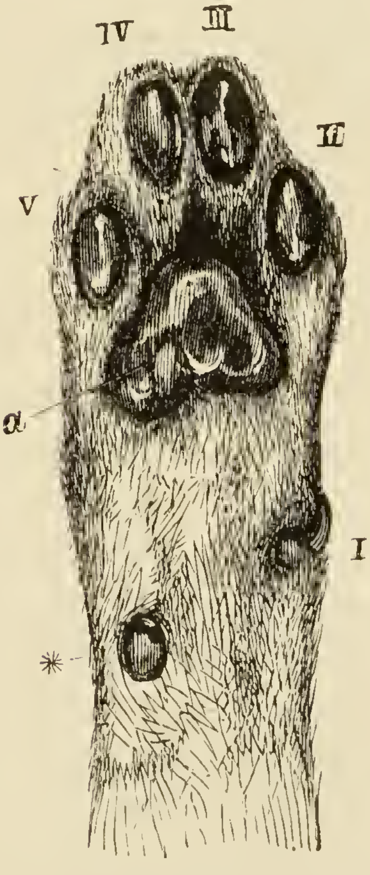

FIG. 154.—Under surface of fore paw. I, II, III, IV, V, the five toes with the pads beneath; *a*, trilobed pad lying beneath the lower ends of the metacarpal bones; *, pad beneath one of the wrist-bones. (From St. George Mivart's "The Cat.")

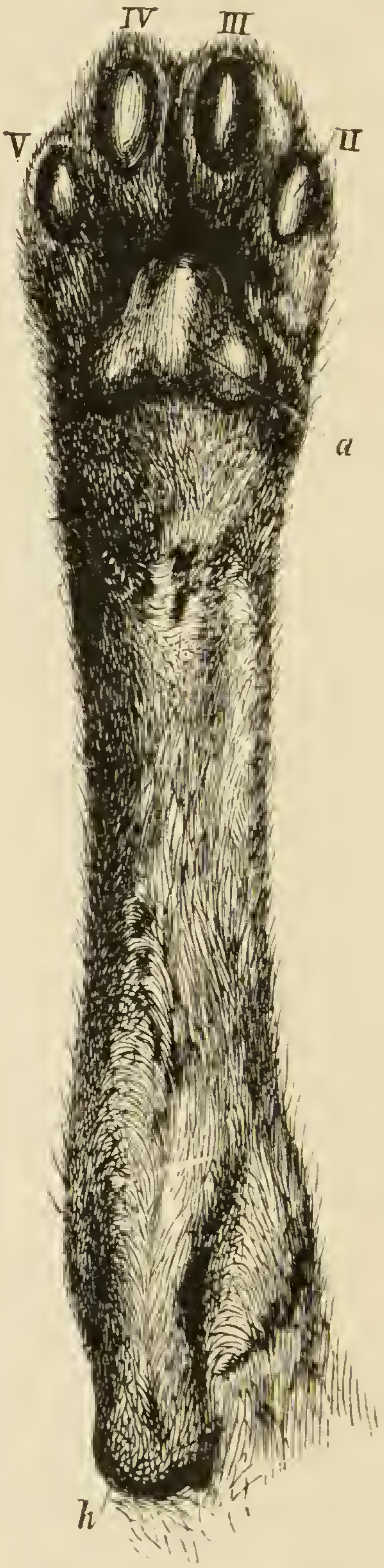

FIG. 155.—Under surface of the hind foot. II, III, IV, V, the four toes with the pads beneath; *a*, pad beneath metatarsal bones; *h*, heel. (From St. George Mivart's "The Cat.")

to escape. They also serve as weapons of offence. When attacked by a dog, the cat arches up her back and erects her tail to increase her apparent size until driven to use her sharp claws on the dog's nose.

For **killing and devouring its prey**, the cat's mouth and teeth are especially well fitted. Holding its victim by means of its sharp claws, the long pointed **canine** teeth are driven like daggers into the flesh and death ensues. The teeth behind the canines are, first, the two premolars on each side of each jaw, with their sharp points fitted for tearing flesh, and then a third tooth on each side (Fig. 150), known as the **sectorial** or **carnassial** tooth. These are large, furnished with a double-pointed cutting edge, and work side by side like the blades of shears. They are thus admirably adapted for cutting and dividing flesh. Moreover, as the points of the two first premolars fit into each other and the sectorial teeth glide past each other, the crowns of these teeth do not wear away (as is the case of the molar teeth of herbivorous animals), but they actually sharpen each other. The incisor teeth in front serve merely for scraping off flesh from bones, and in this action they are aided by the rasp-like action of numerous horny backward-pointed papillæ on the tongue. These papillæ, in the case of the larger cats—lions and tigers—are so large, sharp, and hard that repeated licking of the hand causes it to bleed. A cat can also bend and fold its tongue into a spoon-like shape for lapping milk or water.

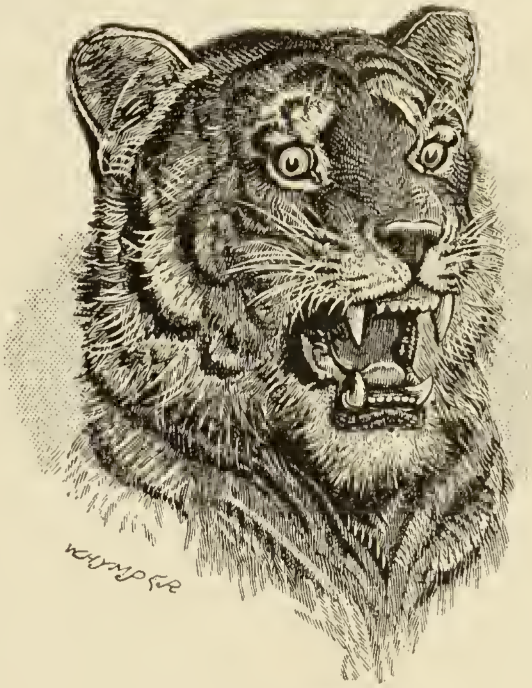

Fig. 156.—Head of tiger.

The mouth of the cat can be opened wide, and this enables it to drive its canine teeth deep, while the jaws are worked by powerful masticatory muscles. As it does not grind its food finely, the gullet is of great width. Animal food, as flesh and milk, being more nourishing than an equal bulk of vegetable food, bulk for bulk, there is not required the same amount of absorbing surface as in herbivorous animals, and the stomach is consequently simple and the intestines relatively short. In the ox and other ruminants, the intestines, on the other hand, are very long.

93. The Cat as a Domestic Animal.—The cat is found as an inmate of the house in almost every land, as it is such a zealous destroyer of mice and rats. It is, however, also fond of killing birds, and in its captures often shows cruelty in playing with its victims. As already pointed out, its bodily structure shows special adaptation for the agile movements necessary in a beast of prey. Some of its mental qualities, moreover, are also well fitted for its predatory habits. Among these may be mentioned the **patience** which it shows lying in wait for its prey; the **cunning** which it exhibits in getting near to prey, or in allowing its victim to approach; and the great **judgment** it shows in selecting the right moment for striking.

Other qualities make the cat a pleasant household companion. She is a particularly clean animal, having a great aversion to wet and dirt. Every part of her fur is kept clean and smoothly arranged by the aid of her tongue and paws, and she carefully covers her excrement with dirt whenever possible. She is also greatly attached to the house in which she is brought up, and will often return from long distances when taken away. It is worthy of note that the attachment is often rather to the dwelling than to the persons in it. She is fond of warmth, and gentle stroking makes her purr with delight. The mother cat is greatly attached to her young. At first the kittens are blind, and the mother feeds, nurses, cleans, and protects them with great devotion. Later, as they are growing up, she teaches them to catch mice and other booty.

The domestic cat is a descendant from some wild ancestor, probably from the desert cat of Abyssinia, and not from the wild cat of European forests. In Britain the wild cat is now almost, if not entirely, extinct. The cat was first domesticated in Egypt in early ages. The ancient Egyptians considered it sacred, and embalmed its body after death. Large quantities of cat mummies are still found in the ancient tombs of this land. From Egypt the domestic cat has spread into all countries. Yet the cat is by nature a wild animal, and sometimes reverts to her ancestral habits, dwelling in a forest, procuring her own food, and bringing up her young in secrecy.

FIG. 157.—Cat creeping up to its prey.

CHAPTER XVII.

CIRCULATION AND RESPIRATION.

94. The Blood.—The blood of man and other mammals, including the cat, is a red fluid circulating in tubes called arteries and veins, and, as it serves to convey to all the solid tissues nutriment and oxygen, and receives certain waste products for excretion, it is important to learn something about its composition and movements.

To the naked eye blood appears as a uniform red liquid, but when examined under the microscope it is found to be a colourless fluid containing an immense number of minute, soft, solid bodies called **corpuscles.** The clear fluid portion of blood is called **plasma**, and is composed of water richly charged with various proteid and fatty materials derived from the food. The minute particles called corpuscles, suspended in the plasma, are of two kinds—red corpuscles and white corpuscles. Examined under the microscope, the red corpuscles are found to be very small *bi-concave discs*, that is, they are round and flat like a coin, but thinner in the middle than at the edge. In diameter they are about $\frac{1}{3200}$ inch, and about one-fourth of this fraction in thickness. So numerous are they that a cubic millimetre (a cube $\frac{1}{25}$ inch on the side) contains about 5,000,000. In a freshly-drawn drop of blood on the slide under the microscope many of them arrange themselves in rows or *rouleaux* like piles of coin (Fig. 158). Red corpuscles owe their colour to a red colouring matter called **hæmoglobin**, and it is to their redness that the colour of blood is due. The white or colourless corpuscles are rather larger than the red, globular or irregular in shape, and of a granular appearance. They also possess a nucleus, which can be rendered visible by a drop of acetic acid on a slide, while the red corpuscles have no nucleus. (The shading in the thinner part of the red corpuscles in the figure must not be taken for a nucleus.) The white corpuscles are also far less numerous than the red (1 white to 350 red). Three white corpuscles only are indicated in Fig. 158. White corpuscles also differ from red corpuscles in the power they possess of changing their shape and moving about like an amœba. They are, in fact, little masses of living active protoplasm. The red corpuscles act as carriers of oxygen between the air and the tissues of the body, as the hæmoglobin of these corpuscles takes up oxygen when the blood is in the capillaries of the lungs, and then gives it up in various parts of the body. The hæmoglobin holds the oxygen in loose chemical combination, and readily parts with it in the presence of substances having a stronger affinity for it.

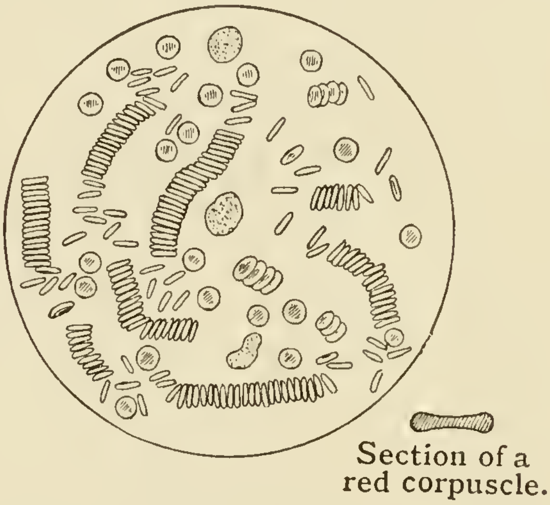

Fig. 158.—Blood as seen under the microscope, showing red corpuscles in rouleaux and singly; also three white ones.

We may now state that the chief uses or functions of blood are (1) to convey nutriment derived by the plasma from digested food to all parts of the body; (2) to convey oxygen taken up by the hæmoglobin of the red corpuscles to all parts of the body; (3) to take in and carry off from all parts certain waste products to the lungs, kidneys, and skin, where they are removed or excreted.

When blood is removed from the body of an animal it undergoes changes. Very soon it thickens or coagulates, and then separates into two parts—a dark red jelly or **clot**, and a clear straw-coloured fluid called **serum**, in which the clot sinks. The clotting or coagulation of blood is due to the change of a proteid substance in the plasma called **fibrinogen** into a solid called **fibrin.** The fibrin consists of stringy threads, which settle down and entangle the corpuscles, so that a clot consists of fibrin and corpuscles. It must be noted that there is no fibrin in living blood, but only a substance, fibrinogen, from which fibrin is formed. On preventing the formation of fibrin by great cold or a solution of certain salts, coagulation is stopped. Fibrin can be quickly separated from blood by stirring it quickly with twigs. The fibrin forms in strings on the twigs, and on being removed and washed, is found to be a soft white substance. The liquid left on removal of fibrin consists only of serum and corpuscles, and is known as "defibrinated blood." It will not clot on standing.

95. The Heart.—The heart is situated in the thorax, between the two lungs, and is enclosed in a membranous bag called the **pericardium**, which is attached to the roots of the great vessels at the base of the organ. It is a conical, hollow organ with muscular walls, divided into four compartments: two auricles above, and two ventricles below; the broad base is uppermost, and the apex below. With the aid of a sheep's heart from the butcher and the following description and figures, its structure and mechanism may soon be understood.

The front of the heart is rounded, and has a groove running from the upper part to the lower, while the back is flatter. The groove marks the position of a septum or division entirely separating the right side from the left. This groove passes near, but not over, the apex of the heart, for the apex belongs to the left ventricle, so that with the front of the heart towards the observer, the left side can be distinguished from the right. The left side is also further distinguished from the right by having stouter and firmer walls for its ventricle.

In the dead heart the auricles are two inconspicuous parts, of a deep purple colour, placed above the ventricles, which form the main bulk. This is mainly due to the fact that the auricles have much thinner walls than the ventricles, and collapse entirely when the heart is empty. Their thin walls may, however, be lifted up with the fingers, so that one can tell that they enclose a chamber.

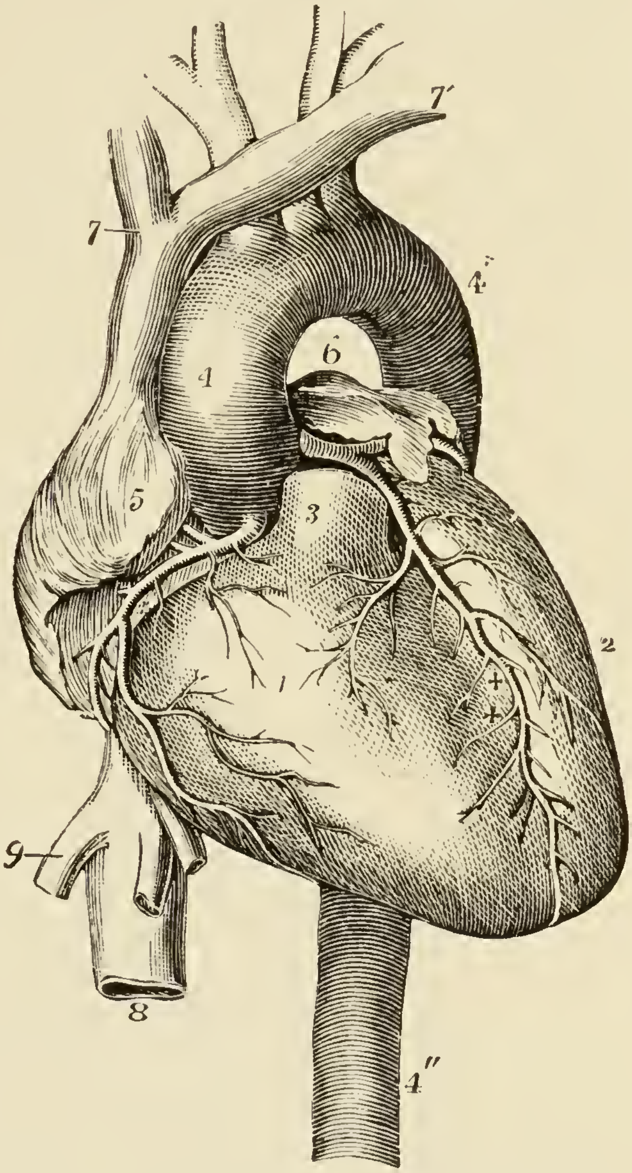

Fig. 159.—The human heart and its vessels, viewed from before. 1, right ventricle ; 2, left ventricle ; 3, root of the pulmonary artery cut short ; 4, 4′, and 4″, the aorta ; 5, right auricle ; 6, left auricle ; 7, 7′, veins which unite to form the vena cava superior ; 8, inferior vena cava ; 9, hepatic vein ; +, coronary arteries. (From Quain's "Anatomy.")

The heart may be regarded as a double organ, composed of a right and left part, completely separated by a partition wall, each side having an upper chamber, the auricle, that communicates with a lower chamber, the ventricle. Flaps of membrane, attached to the inner walls of the heart, between the auricles and ventricles, form valves, which allow the blood to pass from auricle to ventricle, but not in the reverse direction (Fig. 160). Into the right auricle blood passes from the head, neck, and upper extremities by a large vein, called the *superior or upper vena cava*, and also from the lower part of the body by another large vein, the *inferior or lower vena cava* (upper V.C. and lower V.C. in

Fig. 160). From the right auricle the blood passes into the right ventricle through the opening between these chambers, which is guarded by a valve with three flaps, called the *tricuspid valve.* From the right ventricle the blood is forced to the lungs through a large artery that divides into two, called the *pulmonary artery.* It is returned from the lungs by four pulmonary veins into the left auricle. From the left auricle the blood passes into the left ventricle, the opening on the left side being guarded by a valve with two flaps, called the *mitral valve.* From the left ventricle, the blood is forced on the closure of the right valve into a great artery, called the *aorta.*

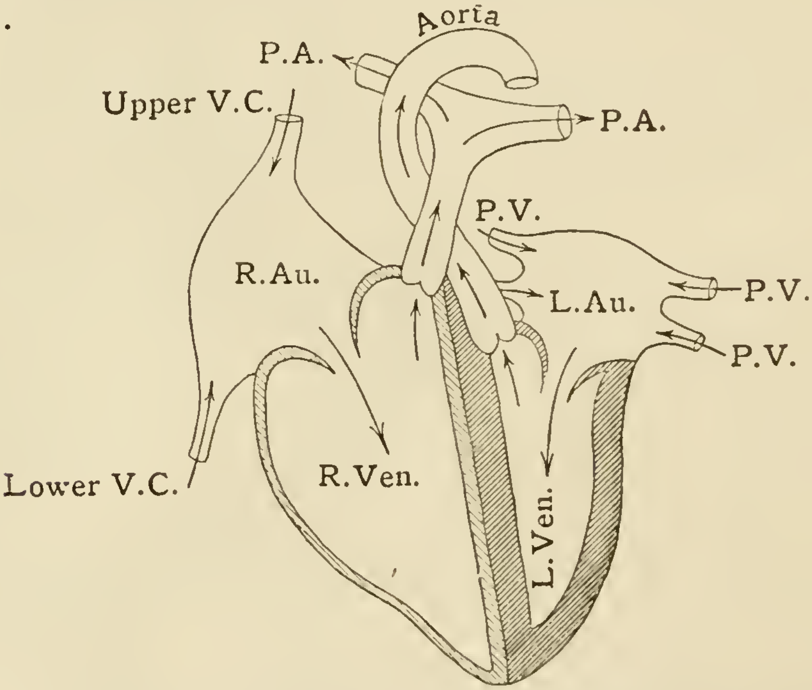

FIG. 160.—Diagrammatic section of the heart of a mammal, to show its chambers and the direction of blood-flow on each side. P.A., pulmonary arteries; P.V., pulmonary veins.

At the beginning of the great pulmonary artery and the great aorta are three watch-pocket-like valves, termed *semilunar valves.* These allow the blood to pass out from the ventricles, but not to flow back (Fig. 161).

The reader should obtain from a butcher a sheep's heart, asking him to leave on as much of the great vessels as he can. The stout aorta will be readily distinguished from the other thinner-walled tubes. Cutting along the aorta, he will find its semilunar valves, where it leaves the left ventricle. Examine the valves between the left auricle and ventricle, and then compare with right side of the heart. Most of the features described above may be readily made out, the sheep's heart being very similar to that of man.

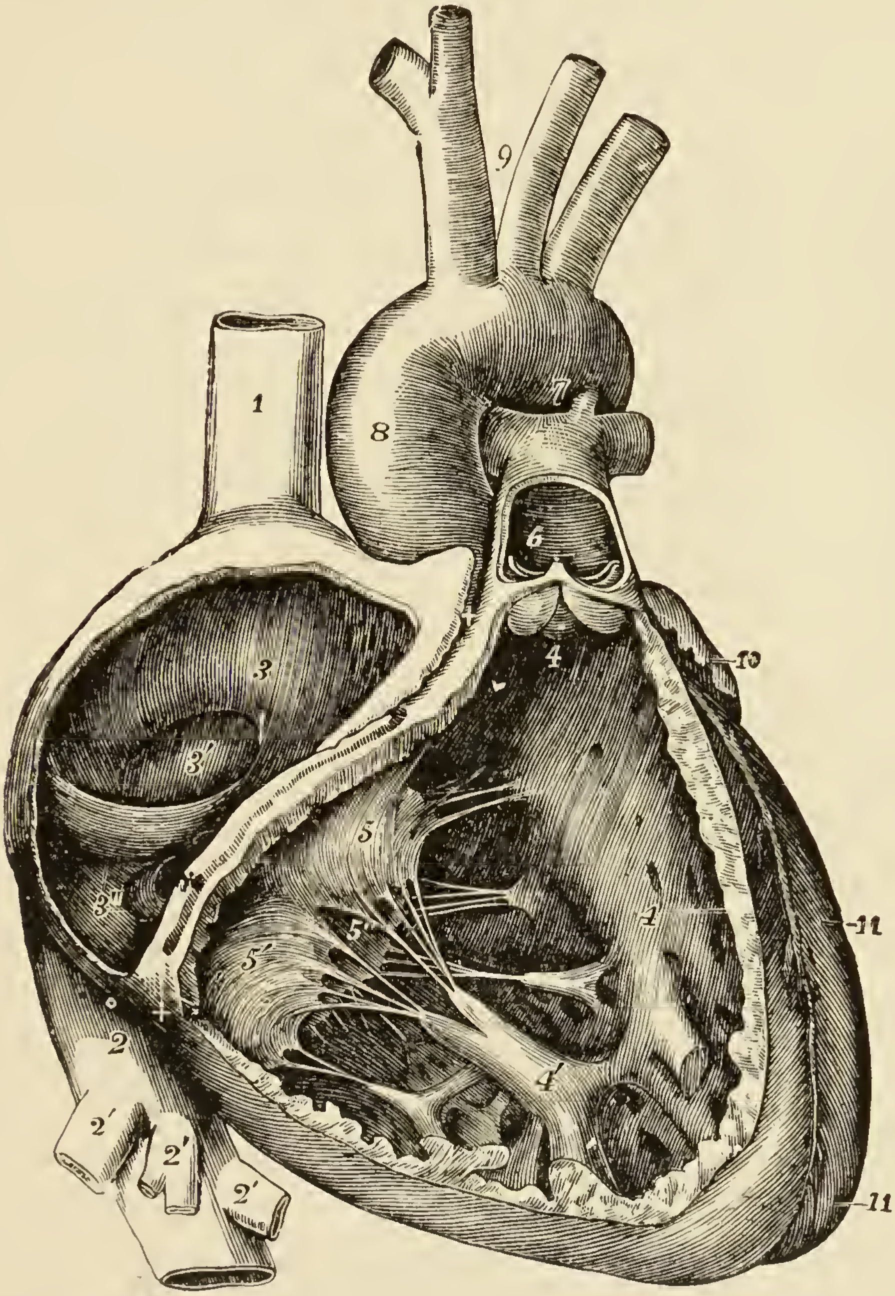

Fig. 161.—Interior of the right side of the human heart. 1, superior vena cava; 2, inferior vena cava; 3, interior of the right auricle; 4, semilunar valves of the pulmonary artery; 4′, papillary muscle; 5, 5′, and 5″, cusps of the tricuspid valve; 6, pulmonary artery; 7, 8, and 9, the aorta and its branches; 10, left auricle; 11, left ventricle.

96. The Circulation of the Blood.—Circulation is the incessant movement of the blood from the heart through a system of closed tubes, called blood-vessels, back again to the heart. The system of tubes or vessels connected with the heart are of three kinds: (1) *arteries*, vessels with relatively stout and elastic walls, which convey blood *from* the heart; (2) *veins*, vessels with thin and flaccid walls, which convey blood *to* the heart, and which are provided with valves like tiny watch-pockets, that allow the blood to pass on towards the heart, but not in the opposite direction; (3) *capillaries*, minute vessels, connecting the arteries and veins, and having walls so thin that they allow a portion of the blood-plasma with its nutriment to escape into the muscle and other tissues through which they pass.

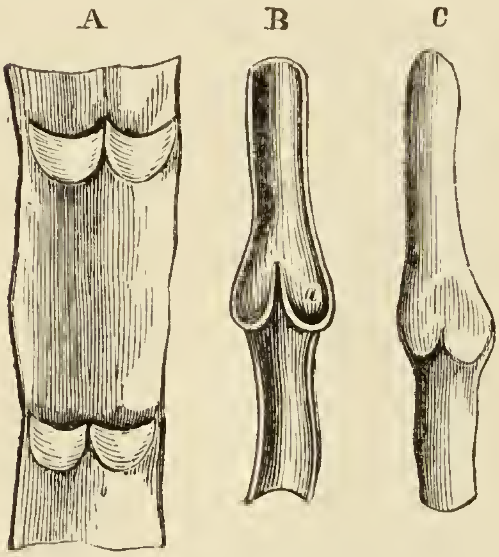

FIG. 162.—Diagram showing the valves of veins. A, part of a vein laid open, with two pairs of valves; B, longitudinal section of a vein, showing the valves closed; C, portion of a distended vein, exhibiting a swelling at a pair of valves. (From Quain's "Anatomy.")

An artery in a dead body may be distinguished from a vein by its thicker walls, and by not collapsing when empty, as a vein does.

To get a somewhat fuller idea of the blood-current, let us begin with the blood in the right auricle, remembering that the heart is a kind of muscular pump that beats or contracts its walls about seventy times a minute. The contraction of the right auricle drives the blood through the opening between the right upper and lower chambers into the right ventricles, the flaps of the tricuspid valve sinking down into the ventricle to allow of this passage. The right ventricle then contracts as the tricuspid valve closes, so that the blood is forced into the great pulmonary artery, from which it passes into the right and left lungs. As the blood passes through the capillaries of the lungs, it gives up carbon dioxide and water-vapour, and takes in oxygen.

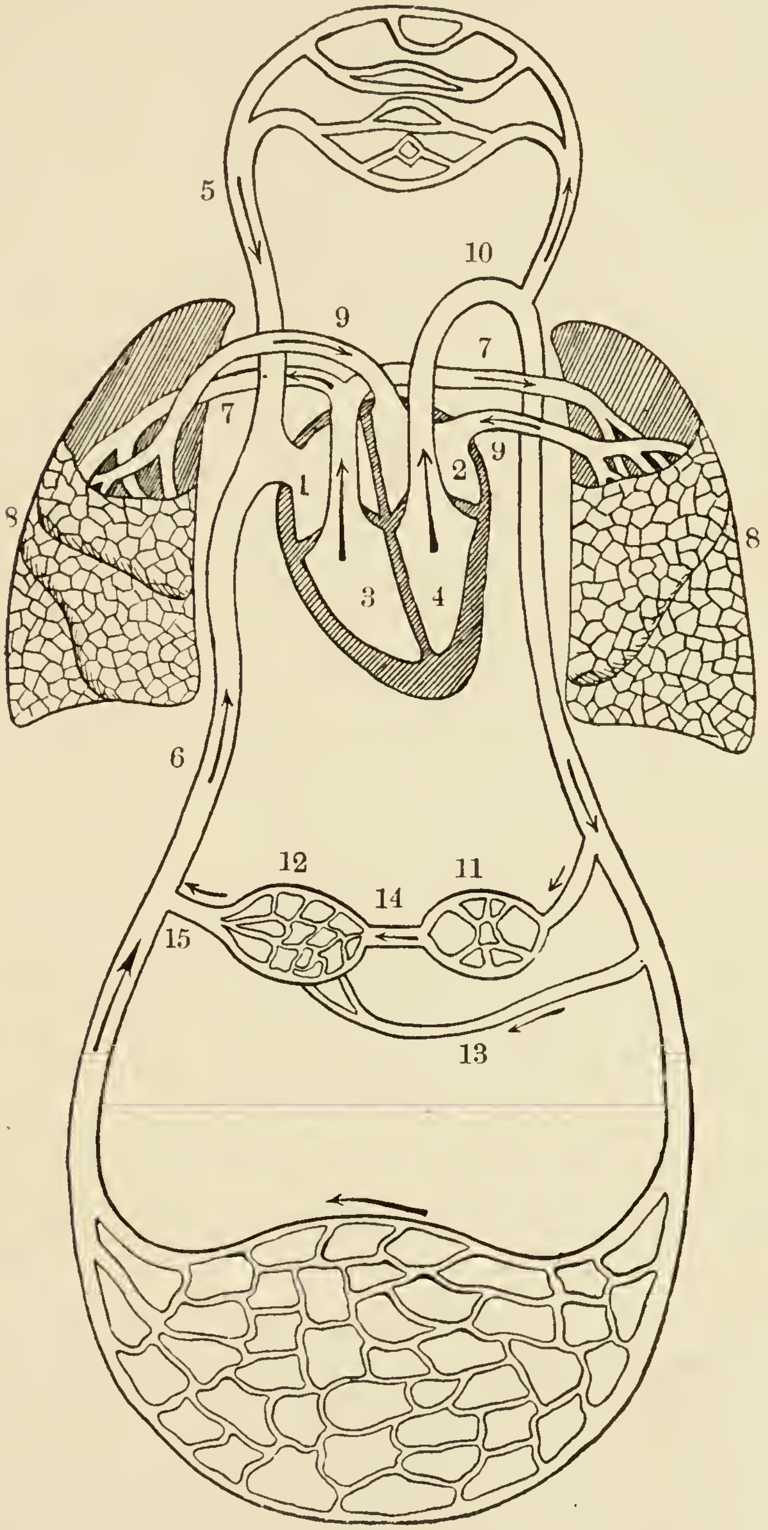

FIG. 163.—Diagram illustrating the circulation. 1, right auricle; 2, left auricle; 3, right ventricle; 4, left ventricle; 5, vena cava superior; 6, vena cava inferior; 7, pulmonary arteries; 8, lungs; 9, pulmonary veins; 10, aorta; 11, alimentary canal; 12, liver; 13, hepatic artery; 14, portal vein; 15, hepatic vein. (From Furneaux's "Elementary Physiology.")

From the capillaries of the lungs, the purified blood passes into veins, which unite to form four main pulmonary veins, that empty into the left auricle. The passage of the blood from the right auricle through the lungs and back to the left auricle is often called the *pulmonary circulation*. From the left auricle the blood is driven into the left ventricle. The contraction of the left ventricle just preceded by the closure of the mitral valve, owing to its two flaps coming together across the opening, forces the blood into the great artery, called the **aorta.** The blood in the aorta is bright red in colour, owing to the oxygen taken up in the lungs, and, laden with nutritive materials obtained before it reaches the right side of the heart (par. 110), passes from the aorta into its branches, reaching smaller and smaller arteries in all parts of the body. From these small arteries the blood passes into capillaries in the tissues of all parts of the body, and through the thin walls of these capillaries there passes out from the blood oxygen and certain dissolved nutriment to the tissues, while from these tissues it receives certain waste products, the effect of these interchanges of material in the tissues being to alter the bright scarlet arterial blood to a purplish venous blood. From the general capillaries the blood is collected into veins, and these veins, from every part of the body, except the heart itself, at last unite into two great veins, the upper vena cava and the lower vena cava, that empty themselves into the left ventricle. This part of the circulation from the left side of the heart, through the aorta, arteries, general capillaries, and veins, back to the right side of the heart, is spoken of as the **greater or systemic circulation.**

A particular part of the systemic circulation is often spoken of as the "portal circulation." The blood that passes to the stomach and other parts of the alimentary canal is collected into a large vein called the portal vein, and this portal vein passes, with a branch of the aorta called the hepatic artery (Gk.

hepar, "liver"), into the liver, where it is broken up into a second set of capillaries, from which capillaries, and those from the hepatic artery, veins termed hepatic veins pass into the inferior vena cava. This "portal circulation" is thus a special part of the systemic circulation.

The diagram (Fig. 163) will help in illustrating the blood circulation. (The reader must, however, remember that a diagram is not a drawing of any actual object or arrangement, but only a figure that helps to illustrate facts in a general or schematic way.)

From one point of view we may regard the circulation of the blood and the circulatory system as formed of two separate parts, as the heart may be looked on as a kind of double organ. The right side of the heart leads to the pulmonary system, its ventricle being the agent for forcing the blood through the lungs; the left side of the heart leads to the systemic circulation, its ventricle forcing the blood through the systemic circulation, and having thicker walls than the right ventricle, as it must force the blood through a greater number of capillaries. Both auricles contract together, and then both ventricles, after which there is a slight pause, when the auricles begin again. This recurrent contraction of the auricles and ventricles is called a *beat* of the heart, and occurs about seventy times a minute. In fact, there is only one circulation, as a drop of blood, to make a complete circuit, must make two journeys from and to the heart.

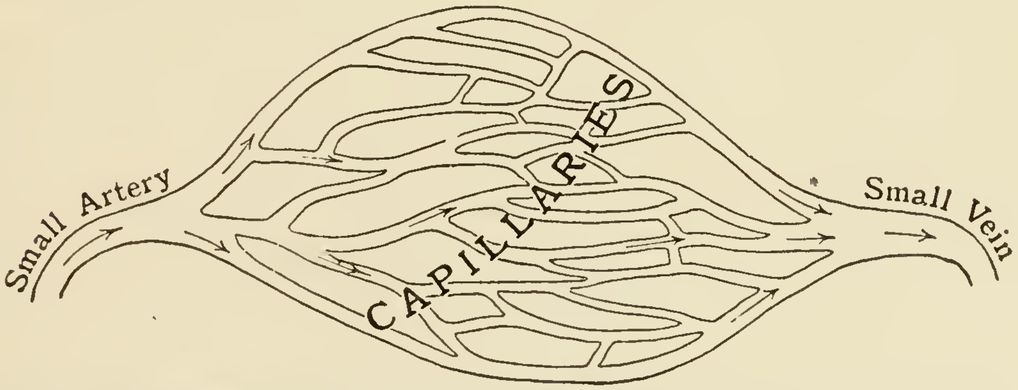

FIG. 164.—Diagram illustrating a small artery splitting up into capillaries, which reunite to form a small vein.

Two noticeable effects of the contraction of the heart and the circulation of the blood may be briefly mentioned. As the heart is turned somewhat to the left, and its apex lies near the chest-wall, at each heart-beat the apex is suddenly pressed against the chest-wall, and this impulse is easily felt between the fifth and sixth ribs, a little below and to the inner side of the left nipple.

Again, as each fresh quantity of blood is sent into the aorta it is suddenly distended, and this distension travels like a wave through all the other elastic arteries. This wave of distension travelling along the arteries is called the **pulse.** The pulse can be felt in any artery that comes near the surface. It is very plain in the artery at the front of the wrist.

97. Arterial and Venous Blood.—The blood in the vessels leading from the lungs in the left chambers of the heart, in the aorta, and in all other arteries of the general circulation, is bright scarlet in colour, and is therefore called **arterial blood.** The blood in the veins of the general circulation, in the right chambers of the heart, and in the vessels leading from the right side of the heart to the lungs, is darker and of a reddish-purple. This reddish-purple blood is called **venous blood.** The change from scarlet arterial blood to purple venous blood takes place as it passes through the tissues of all parts, for in these tissues it gives up oxygen and takes in carbon dioxide produced in the tissues. The change of dark venous blood to bright arterial blood takes place as the blood passes through certain minute capillaries of the lungs; for it is there separated from the air of the lungs by very thin membranes through which a gas can pass, and it consequently gives up carbon dioxide to the air in the lungs and takes oxygen from this air. Oxygenated blood is bright scarlet, and blood that gives up part of its oxygen for carbon dioxide is a reddish purple.

The venous blood is taken from the right ventricle to the lungs by the pulmonary artery and its branches, and it is not until it passes into the lung capillaries that it gives up carbon dioxide and takes in oxygen and so becomes bright scarlet in colour. Hence the pulmonary artery and its branches contain dark venous blood, though all other arteries contain bright arterial blood, as before stated. The changed and purified blood is brought from the lungs by the pulmonary veins, so that these veins contain bright arterial blood, though all other veins, as just stated, contain dark venous blood.

The change of colour in blood may be seen if the reader will obtain some defibrinated blood from a butcher (par. 94). Defibrinated blood does not clot. Put some defibrinated blood into a bottle, and bubble in carbon dioxide gas. It becomes dark and purplish in colour. Now pass in oxygen, or shake it up with the air, and it becomes bright scarlet. It is the red corpuscles that take up and give out oxygen, or rather it is the peculiar substance termed *hæmoglobin* contained in the red corpuscles that does this.

Respiration is the process of taking up oxygen and giving out carbon dioxide. To understand better how this is effected in man, the cat, or any other similar animal, we must describe the respiratory organs and the passages connected with them.

98. The Organs of Respiration.—The lungs are the chief organs of respiration. At the back of the mouth is a funnel-shaped cavity called the **pharynx.** The pharynx is connected with the outer air in two ways—by the nostrils and nasal passages, and by the mouth (Fig. 165). From the pharynx a tube at the front of the neck, called the **trachea,** or windpipe, leads into the lungs; while another tube, the **œsophagus,** or **gullet,** behind the pharynx, leads into the stomach. The upper end of the trachea has a kind of box called the larynx, in which the voice is produced. In the larynx is a chink called the **glottis,** which is bounded by two folds of membrane called the **vocal cords.** The trachea is guarded by a leaf-like lid, the **epiglottis**, which can fall over so as to prevent particles of food getting into it (Figs. 165 and 172). The trachea, or windpipe, is about four inches long and three-quarters of an inch wide, and

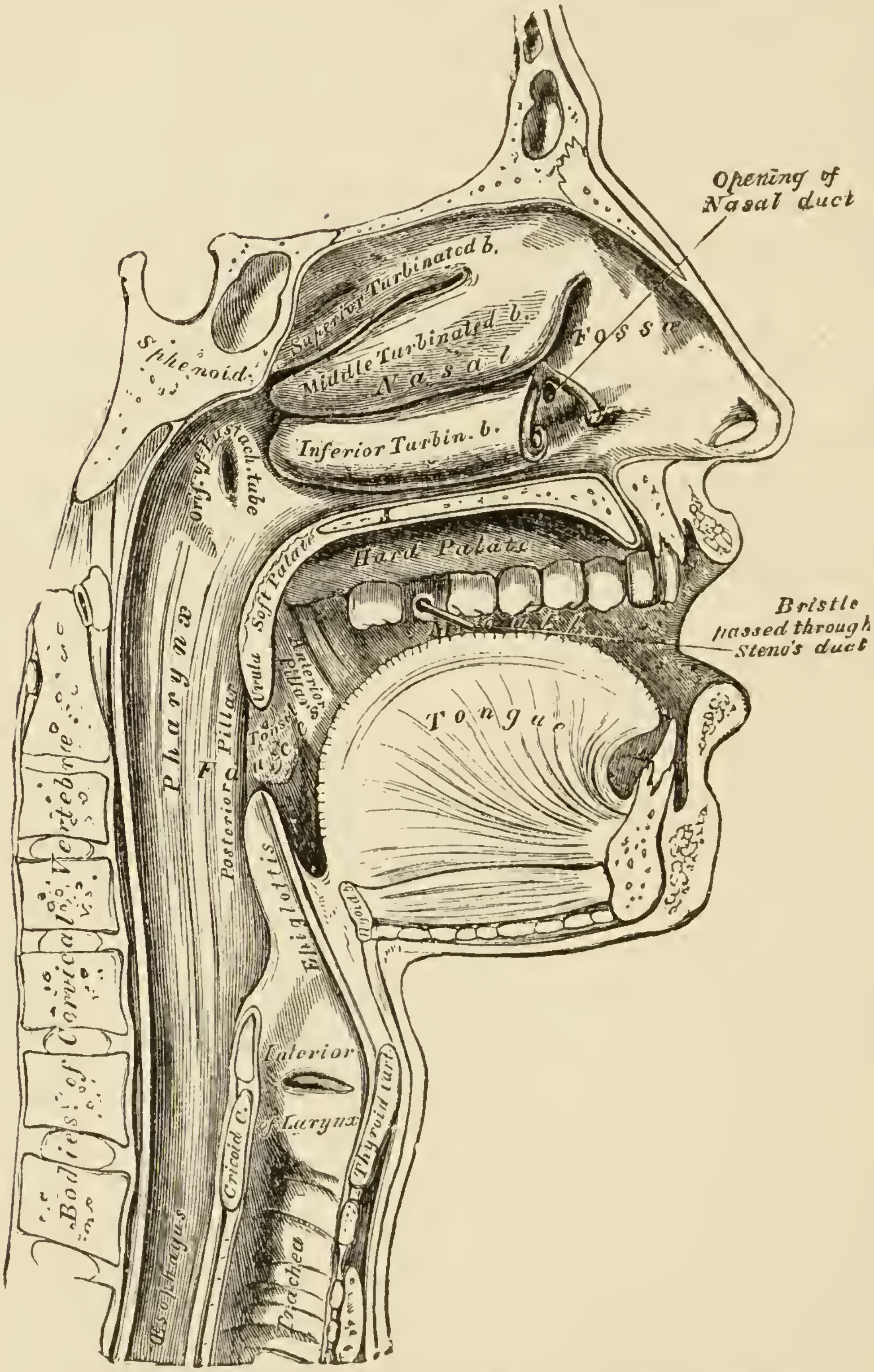

Fig. 165.—The mouth, nose, windpipe, and gullet seen in section. (From Gray's "Anatomy.")

passes down the front of the neck into the thorax. It is made up of rings of cartilage, incomplete behind, and soft muscular and fibrous tissue. At its lower end, in the upper part of the thorax, the trachea divides into two branches called **bronchi**, the right bronchus leading into the right lung, and the left bronchus leading into the left lung. The bronchi divide and subdivide in the lungs into **bronchial tubes** that penetrate every part of these organs.

The lungs are the pinkish-grey, spongy, elastic organs that fill up the whole cavity of the chest not occupied by the trachea, heart, and great blood-vessels. They consist of connective tissue, blood-vessels, and a complicated system of air-tubes and air-cells. The bronchial tubes divide into smaller and smaller branches, until they become too minute to be seen by the unaided eye. Each minute bronchial tube ends blindly in a group of tiny air-sacs much wider than itself. The dilated termination of each bronchial tube is termed an **infundibulum**, and each infundibulum is divided into a number of tiny chambers called air-cells, or **alveoli.** Imagine a bunch of grapes with its stem and branches, and the grapes themselves all hollow, and you get some idea of the structure of the lung, only the walls of the grapes should be raised into tiny pouches to represent the air-cells of the infundibula. It is because there is always air left in these cells that the lungs from an animal killed by the butcher have such a soft, spongy feeling, and crackle when pressed. The butcher calls them "the lights," because when a lung, or a piece of one, is thrown into water, it floats.

The lungs consist of bronchial tubes and groups of air-cells that form the dilatations at the end of the smaller ones, of numerous blood-vessels, nerves, and lymphatic vessels, and of connective tissue binding all together into a spongy mass. The walls of these minute air-cells consist of the thin inelastic connective tissue, and in this connective tissue lie the very fine pulmonary capillaries, so that the blood in the capillaries is separated from the air in the air-cells only by the thin capillary wall and a very thin layer of the tissue. The moist partition between the blood in the capillary network on the air-cells is so thin that it allows of an interchange between the gases of the blood and the gases of the air in the air-cells—that is, carbon dioxide passes outwards from the blood into the air-cells, and oxygen passes from the air-cells into the blood, so that the dark venous blood that is brought to the pulmonary capillaries is changed into bright scarlet blood before it leaves them.

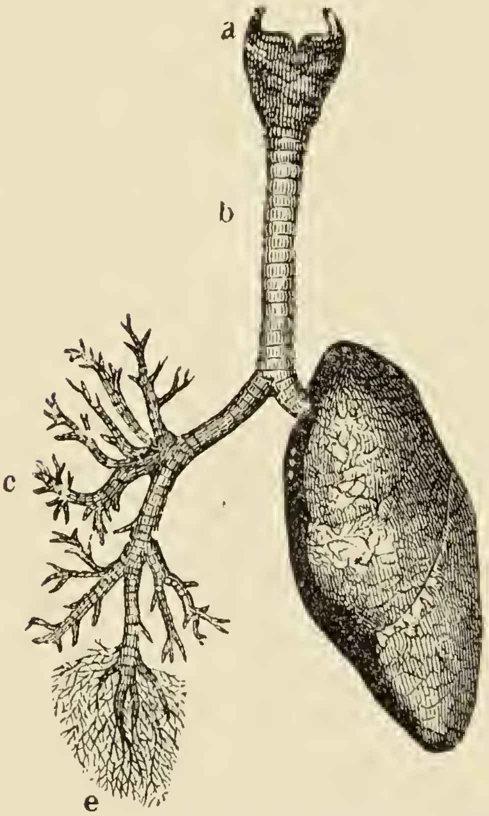

FIG. 166.—The lungs, showing on one side the bronchial tubes only. *a*, the larynx ; *b*, trachea ; *c*, bronchial tubes ; *e*, ultimate bronchial tubes.

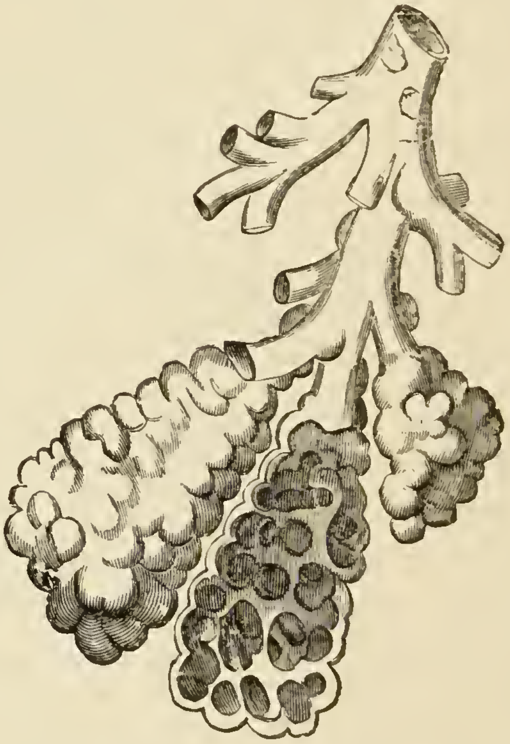

FIG. 167.—Three infundibula with air-cells at the end of the ultimates or smallest bronchial tubes (highly magnified).

Each lung is covered by a smooth shiny membrane called the **pleura**, and this membrane is reflected or bent back upon the internal wall of the thorax ; but between the layer of pleura on the lung and that on the internal wall of the thorax there is hardly any space, for the atmospheric pressure passing down the trachea and bronchial tubes causes each lung to fill its own side of the thorax.

99. Inspiration and Expiration.—When we take the lungs supplied by a butcher, and blow into them, they expand and then shrink when left to themselves. This is owing to the large amount of elastic tissue in them. The force exerted in blowing into them expands them, but the outside atmospheric pressure causes them to shrink when the blowing is withdrawn, though there is always some air left in them. Now, in the natural condition in the thorax, the lungs are protected from the outside pressure of the air by the walls of the thorax, but the atmospheric pressure down the trachea and through the bronchial tubes into the air-cells keeps them, as before said, in close contact with the inner walls of the chest, so that they fill up each side of the thorax completely.

If the cavity of the thorax is increased in any way, the pressure of the atmosphere passing down the trachea distends the lungs, and more air passes into them; if the cavity of the thorax is diminished in any way, the lungs are forced to shrink in size, and air is drawn out of them.

Now, the air in the lungs is constantly being renewed by respiratory movements that alternately enlarge and diminish the cavity of the thorax, the enlargement and contraction of the lungs accompanying those of the thorax. This renewal of the air in the lungs is necessary, as the air in the alveoli, or air-cells, soon becomes unfit to convert venous blood into arterial, owing to its loss of oxygen and gain of carbon dioxide. It must therefore be mixed with fresh air from the outside at frequent intervals, in order to render it fit for its office.

Respiration, or the act of breathing, may be regarded as a double act, consisting of **inspiration** and **expiration**, the double act taking place in the adult at rest about 16 to 20 times a minute.

Inspiration is the act of drawing air into the lungs through an increase in the size of the cavity of the thorax.

and this is brought about in two ways—by the contraction of the muscular partition at the floor of the thorax, called the diaphragm, and by the contraction of the intercostal and other muscles. When the diaphragm contracts, it becomes flatter and makes the chest deeper in its widest parts. When the external muscles between the ribs (the external intercostal muscles) contract, they aid with other muscles in raising the ribs and pushing out the sternum so as to increase the thorax from front to back. As already explained, the increase of the cavity of the thorax causes air from outside to rush into the lungs, and this fresh air mixes by diffusion with the air in the smaller bronchial tubes and air-cells.

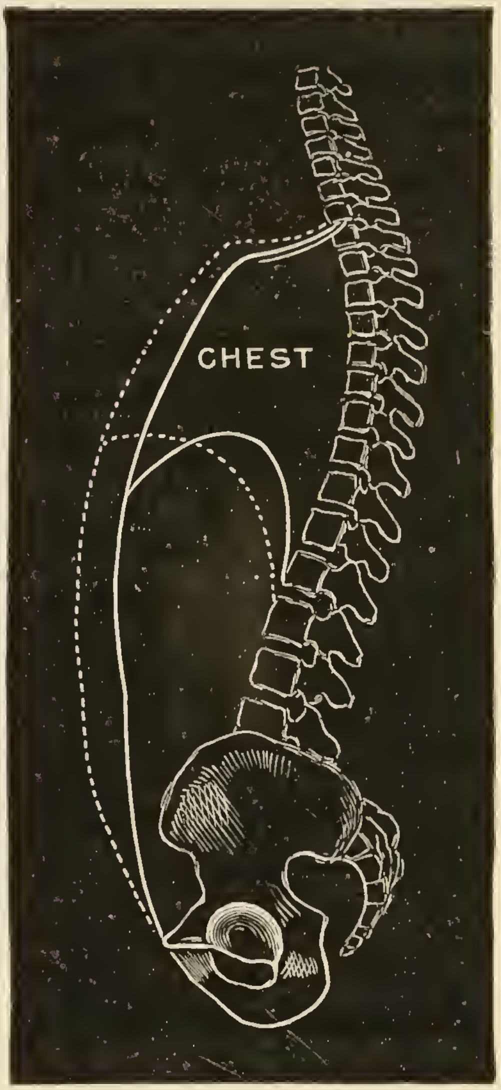

Fig. 168.—Inspiration and expiration. (After Huxley.) The dotted line shows the effect of a full *inspiration* and how the cavity of the thorax is increased thereby. (From Paul's "Domestic Economy.")

Inspiration is thus produced by considerable muscular effort, for the diaphragm must contract and push down the viscera in the abdomen, and the ribs and sternum have to be raised by muscular contraction. But expiration, or the act of forcing air out of the lungs, requires, in ordinary breathing, but little muscular effort, and is due mainly to the elasticity of the lungs and the falling down of the ribs and sternum by their own weight as soon as the muscles which raised them relax.

100. Quantity of Air respired and the Changes in

Respired Air.—At each ordinary inspiration an adult takes in about twenty-five cubic inches of air, and sends out the same quantity at the next expiration. This moving quantity is called the **tidal** air. At the end of the expiration there still remain about two hundred cubic inches of air in the lungs, called the **stationary** air. The tidal air taken in at each inspiration rapidly mixes by diffusion with the stationary air, some of which passes upwards, and in this way the air in the air-cells is continually obtaining a new supply of oxygen for the blood of the capillaries, and giving up carbonic acid to be expired. By increased muscular effort more air may be inspired than in an ordinary inspiration, and more air forced out than in an ordinary expiration. But after the most forced expiration, there always remain about one hundred cubic inches of air in the lungs.

The composition of the air entering the lungs differs considerably from the expired air.

Ordinary dry air consists of the following percentage of gases by volume :—

Nitrogen	79·02	per cent.
Oxygen	20·96	,,
Carbon dioxide	0·04	,,

But ordinary air is never dry, as it always contains a variable quantity of invisible water-vapour.

Expired air, when dried, consists of—

Nitrogen	79·58	per cent.
Oxygen	16·04	,,
Carbon dioxide	4·38	,,

Expired air is always saturated with water-vapour derived from the moist air-passages through which it has passed, contains a small amount of organic impurities, and is in ordinary climates warmer than the inspired air. The large amount of moisture in expired air may be readily shown by breathing on a cold glass, when much of the water-vapour is condensed. Breathing into lime-water and noting the milky precipitate readily show that expired air contains much carbon dioxide (" Elem. Physiog." sec. 1, par. 153). We may therefore say that air that has been once breathed differs from pure air as follows :—

(*a*) It contains more carbon dioxide.
(*b*) It contains less oxygen.
(*c*) It contains more water-vapour.
(*d*) Its temperature is greater.
(*e*) It contains some organic impurities.

The average man breathes (inspires and expires) about sixteen or seventeen times a minute, so that in a *day* about 280 cubic feet of air pass in and out of the lungs. The oxygen taken in amounts to 1·65 lb. The expired air contains about 2 lbs. of carbonic acid and 1½ pint of water, and is usually warmer than that taken in. There is, therefore, through the lungs both a loss of matter and a loss of energy in the form of heat.

101. Hygienic Remarks on Air and Breathing.—It is evident, from what has been said, that wherever men or other animals are crowded together in rooms or other such enclosed spaces, the oxygen of the air in the space will soon be diminished and the quantity of carbon dioxide increased. Lights and fires produce the same results. Further, from the lungs and skin of animals organic vapours and impurities are given off that produce a stuffy and uncomfortable feeling. It follows that all such rooms need **ventilation**, by which is meant the dilution and removal of the vitiated air and the admission of fresh, pure air. Ordinary fresh air contains 0·04 per cent. of carbon dioxide, or 4 volumes in 10,000 volumes of air, and it is found that the amount of carbon dioxide should not be allowed to exceed 0·06 per cent., or 6 volumes in 10,000 volumes of air, if injury to health is to be avoided.

Again, since both chest and abdomen alternately expand and contract in respiration, any clothing or covering that impedes the natural movements or unduly constricts any of these parts of the body should be avoided, otherwise an undue amount of work is thrown on the muscles, and deformity may also be produced.

CHAPTER XVIII.

THE ORGANS OF DIGESTION AND THE PROCESSES OF DIGESTION.

102. General Account of the Alimentary Canal.—The digestive canal, often called the **alimentary canal** (Lat. *alo*, "I feed"), is a long complicated tube running through the body from the mouth to the lower end of the spine, in some places narrow and in others wide, in some parts straight and in others coiled up, and having at certain points small tubes leading into it from organs connected with it, called the liver and the pancreas (sweetbread). Beginning at the mouth, it is continued through the thorax as the **œsophagus**, or **gullet**. The gullet passes through the diaphragm, and then at once swells out into a bag called the **stomach**. It then narrows again into the **small intestine**, which lies in coils in the central part of the cavity of the abdomen. The small intestine, which is about twenty feet long, then swells out into a wider tube called the **large intestine**, and this, after turning upwards, across, and then downward, terminates at the opening called the **anus**.

The interior of this long digestive tube is lined throughout by soft, moist, reddish kind of skin called **mucous membrane**. Bands and layers of muscle with some connective tissue form its outer walls, and in these walls are minute blood-vessels and some absorbent tubes called lacteals.

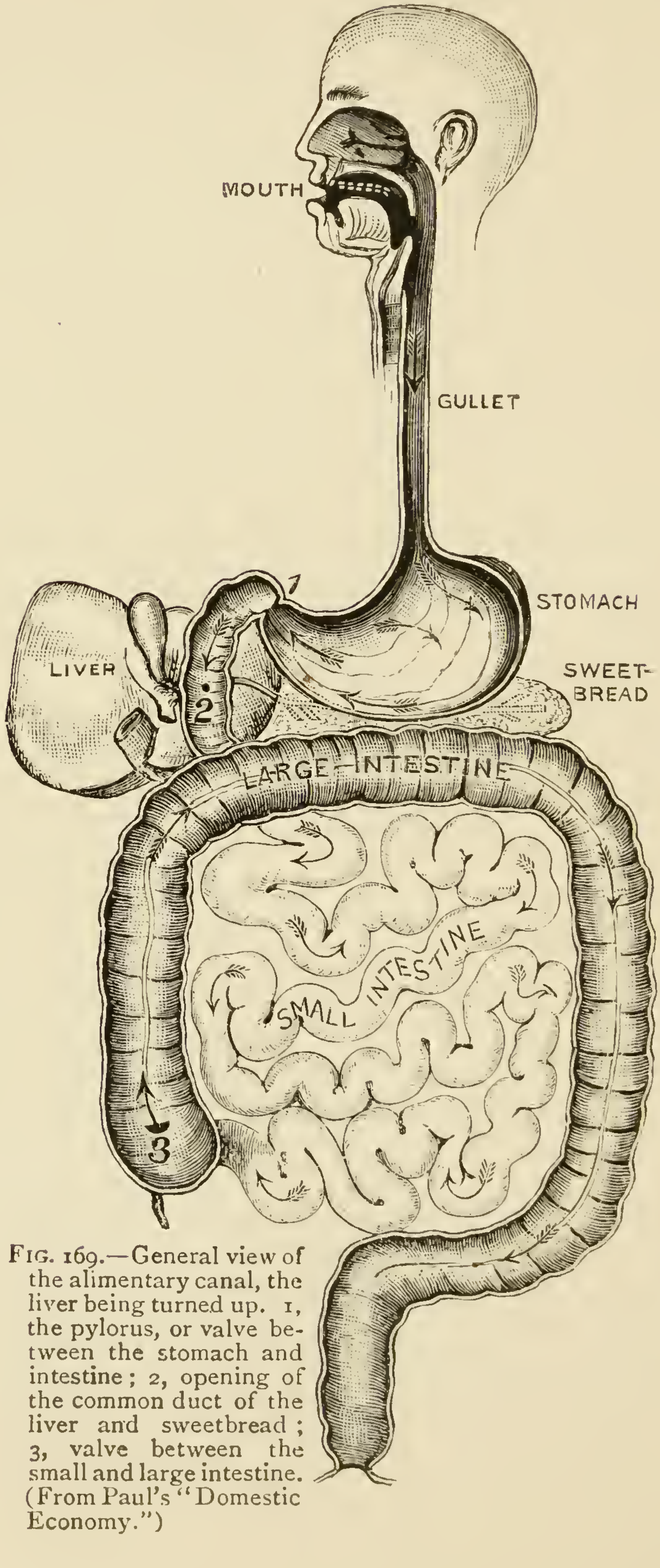

Fig. 169.—General view of the alimentary canal, the liver being turned up. 1, the pylorus, or valve between the stomach and intestine; 2, opening of the common duct of the liver and sweetbread; 3, valve between the small and large intestine. (From Paul's "Domestic Economy.")

Now, we have already stated that there is a constant waste of tissue in every part of the body where any kind of activity is going on, and that this waste is made good by material brought to the tissues by the capillary blood-vessels in them. But how does the food get from the alimentary canal into the blood contained in the vessels in its walls? There are no visible openings anywhere in the canal which communicate with these blood-vessels, yet we know that the food is in some way absorbed into the blood.

103. General Statement about Digestion and Absorption.—Digestion is the process, or rather a series of processes, by which food is converted into materials that can be absorbed into the blood. We know from the experiments described in par. 48 that a solution of salt or sugar separated from water by an animal membrane, such as a piece of bladder, gives up some of its salt or sugar to the water, while a current of water is set up in the opposite direction. The passage of substances in solution through the invisible pores of such a membrane is called **osmosis**, or **dialysis.** Whenever there are two solutions different in strength, separated by a porous membrane, like a bladder or a cell wall, an interchange between them takes place (par. 48).

Now, after a meal, there is in the stomach and intestines a quantity of liquid food, many of the substances of which are in solution. Between these dissolved substances and the blood-stream there is only a membrane formed by the very thin walls of the blood-capillaries and a thin portion of the wall of the alimentary canal. Among the substances in solution in the stomach and intestines will be sugar and salt, and the solution of these in the canal being stronger than in the blood, we can easily see that these will pass through the membrane into the blood by osmosis (par. 48). But there will be in the stomach and intestines, besides sugar and salts, such substances as starch, gluten, albumen, and fat, and these are found on trial not to pass through a membrane.

If we place, for example, water with some white of egg (albumen), and some starch along with sugar and salt, in the bulb of the thistle funnel, over which we have tied some membrane (Fig. 80), and then place this bulb in water, we shall find after some time that while the salt and water have dialyzed, or passed through the membrane, the starch and the albumen do not pass at all. Hence we see that while sugar and salts can readily pass into the blood in the walls of the alimentary canal, such substances as starch and albumen must be changed in some way before they can be absorbed. To do this, different secretions are poured into the alimentary canal to act in various ways on the food-stuffs, so as to render them capable of being absorbed. Thus saliva has the power of changing starch into sugar, and gastric juice from the stomach can convert albumen into a substance called peptone, which will pass into the blood. Fat is another substance which will not pass through a membrane, but when acted upon by soda compounds in the bile from the liver, it becomes able to pass through a membrane.

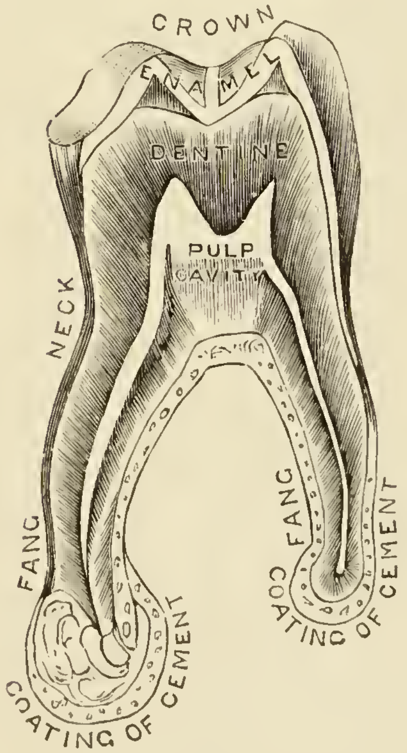

Fig. 170.—Section of a tooth. (From Barnett's "Making of the Body.")

With these general remarks we proceed to consider more fully the organs of digestion and the digestive processes.

104. Digestion in the Mouth.—The first part of the process of making the food soluble, so that it can be absorbed into the blood-vessels of the alimentary canal, begins in the mouth. The mouth is a kind of box with a movable floor formed of the lower jaw and the tongue. At the top, in front, is the hard palate, and behind this a soft palate; at the sides are the cheeks and teeth, and in front are the lips and some teeth. When food is taken into the mouth it is cut and ground by the teeth. The teeth, which number thirty-two in the adult, have already been partly described (par. 79). Their variety is suitable to the mixed character of the diet on which man lives. Every tooth consists of a projecting part called the crown, and one or more fangs embedded in the jaw-bone. Inside each tooth is a hollow containing a pulpy matter, to which are supplied blood-vessels and a nerve through a tiny hole at the end of the fang. The exposed part of a tooth, the crown, is coated with a very hard white substance called **enamel**; beneath this is the mass of hard substance, like bone, called **dentine**, which forms the main part of the solid material. The fang part of the dentine is, however, covered with another kind of bony substance called **cement** (Fig. 170).

The function of the teeth is the mechanical work called **mastication**,—the grinding and breaking-up of the food. During mastication, the food is being mixed and moistened with a fluid called **saliva**, which flows into the mouth from a number of small glands called salivary glands,[1] each gland opening into the mouth by a small tube or duct.

There are six salivary glands: two **parotid** glands, one below and in front of each ear, two **submaxillary** glands under the lower jaw, and two **sublingual** glands in the floor of the mouth under the tongue. The saliva not only mixes and softens the food, but it contains a ferment that acts upon the starch portion of the food in such a way that some of this starch is changed into a kind of sugar (grape sugar). As already stated (par. 12), starch is insoluble, and cannot therefore be absorbed, but when changed by the saliva, it is ready to be absorbed when it reaches the stomach.

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[1] Glands are organs of various shapes and sizes, whose special work is to draw out something from the blood. A **secretion** is something, usually a liquid prepared from the blood, to be used again by some part of the body for a special purpose. An **excretion** is something separated from the blood, in order to be discharged from the body. Thus the salivary glands secrete from the blood capillaries in their substance saliva, in order that it may be mixed with, and act upon, the food in the mouth, while the liver secretes bile to be mixed with the food when it reaches the small intestines. Small coiled tubes in the skin, opening by pores on the surface, separate from the blood the excretion called sweat, while the kidneys separate water and the waste nitrogenous substance called urea from the blood, and the water with the dissolved urea, after accumulating in the bladder, is discharged.

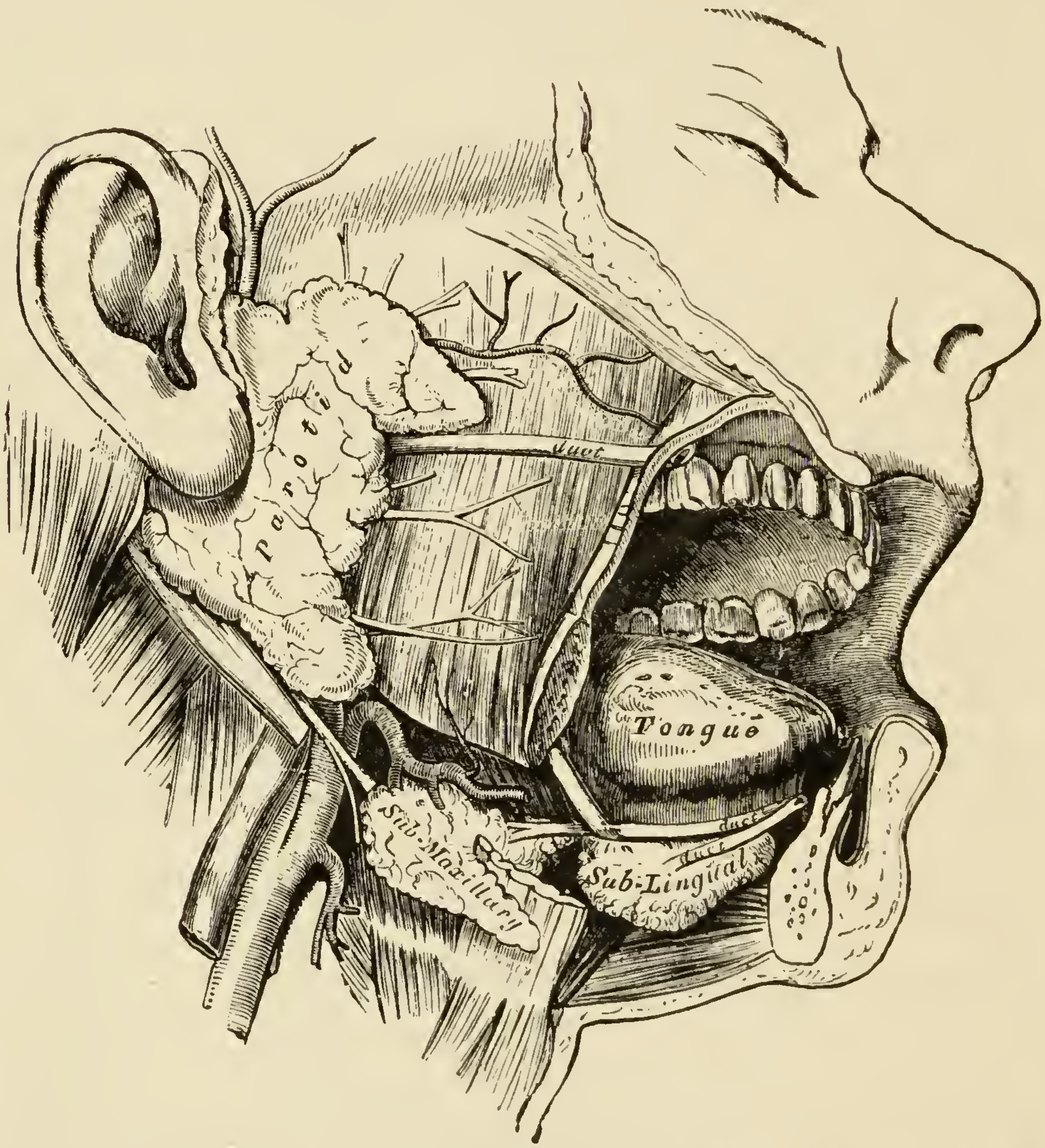


FIG. 171.—The salivary glands. One side of the lower jaw has been removed, and the face dissected, in order to show the salivary glands of the right side. (From Gray's "Anatomy.")

This action of starch may be noted by placing some boiled starch in the mouth and by keeping it there two or three minutes. It will then be noticed that it becomes more watery and acquires a sweetish taste. The importance of well masticating the food, so as to allow it to mix with the saliva, is evident. Other reasons will presently appear.

105. Swallowing.—After the food has been masticated and mixed with the saliva, it is carried to the back of the tongue and passed into the funnel-shaped cavity at the back of the mouth called the pharynx (see Fig. 172).

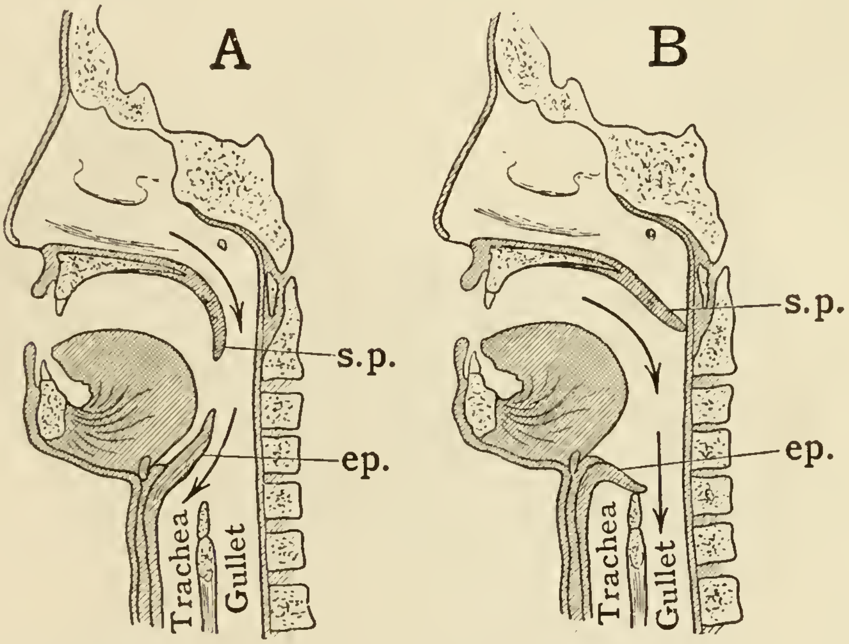


Fig. 172.—Showing position of soft palate and epiglottis during (A) respiration and (B) swallowing (compare with Fig. 165).

The soft palate, with its **uvula,** is raised so as to prevent the food passing into the hinder nasal passages, while the leaf-like lid of the trachea, called the **epiglottis,** falls over the entrance to the windpipe, and thus prevents the food from going "the wrong way." If this should happen to a morsel, violent coughing follows to throw it out. The passages both into the nose and the trachea being closed, the mass of food passes from the pharynx into the top of the gullet. It is then driven along this tube by the action of its muscular walls, which contract above it and push it along, somewhat in the same way as we can make a marble run along a rubber tube of smaller diameter. Food does not simply fall down the gullet, but is pushed along as described, so that it is possible to drink water or swallow food with the head downwards. Watch a horse eating grass or drinking water, and the wave-like contraction of the gullet behind the food will be readily noticed.

106. Digestion in the Stomach.—The stomach is a pear-shaped expansion of the alimentary canal, with the broad end to the left and the narrow end to the right. It lies just beneath the diaphragm, and has two openings, the **cardiac** orifice, through which the food enters, and the **pylorus**, by which the food leaves the stomach to pass into the small intestines (Fig. 173).

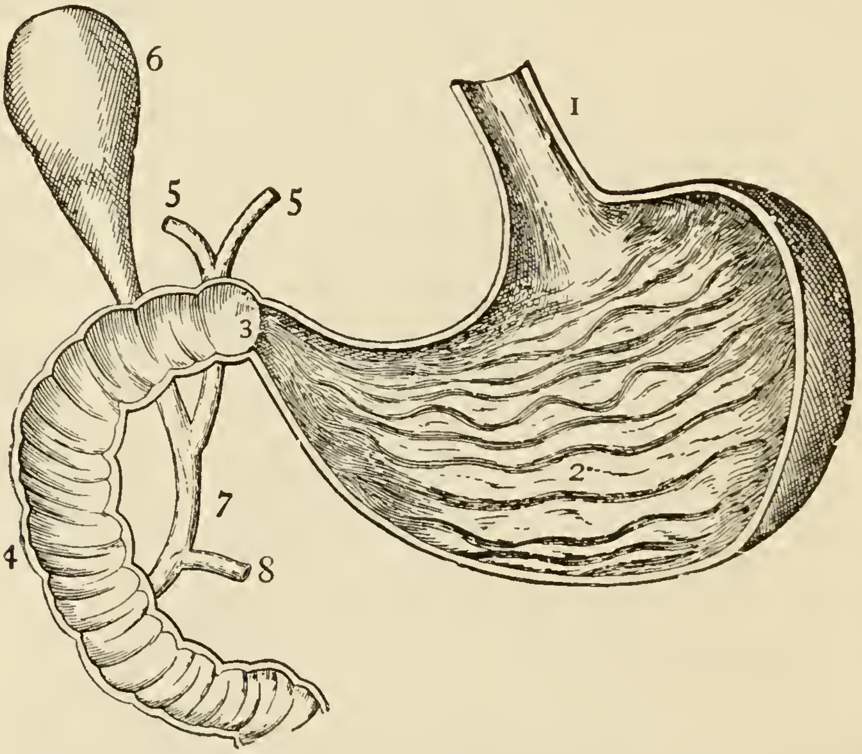


Fig. 173.—The stomach and the duodenum, laid open to show the mucous membrane. 1, œsophagus; 2, mucous membrane of the stomach; 3, pylorus; 4, duodenum; 5, the ducts which convey the bile from the liver; 6, gall-bladder; 7, common duct; 8, the pancreatic duct. (From Furneaux's "Elementary Physiology.")

The walls of the stomach consist of four coats, which are, passing from the outside inwards:—

(1) An outer coat of fibrous tissue; (2) a muscular coat

formed of a layer of longitudinal muscular fibres, within which is a layer of circular and oblique muscular fibres; (3) a submucous coat of connective tissue, in which are the larger blood-vessels; and (4) a mucous coat, containing a large number of small tubular glands, among which is a network of capillary blood-vessels. The inner mucous coat is next the food, and if examined with a lens it presents a peculiar honeycombed appearance, owing to the immense number of shallow pits, which are the mouths of the small ducts that form the glands of the stomach. These gastric glands during digestion pour into the stomach a thin, colourless acid fluid called the **gastric juice.** Gastric juice is a very watery solution of certain salts, hydrochloric acid, and a ferment called **pepsin** (Lat. *pepto*, "to cook or digest").

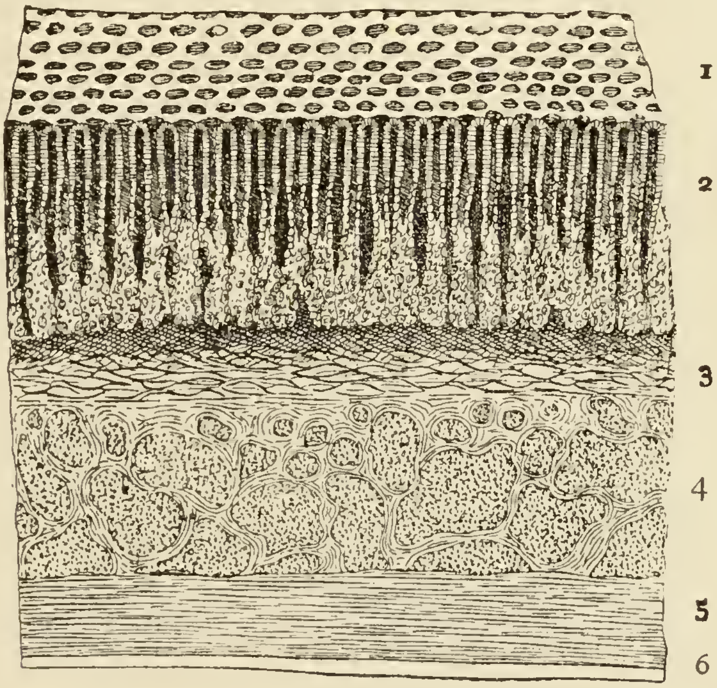


FIG. 174.—A section through the walls of the stomach (magnified 15 diameters). 1, surface of the mucous membrane, showing the openings of the peptic glands; 2, mucous membrane, composed almost entirely of glands; 3, submucous or areolar tissue; 4, transverse muscular fibres; 5, longitudinal muscular fibres; 6, peritoneal coat. (From Furneaux's "Elementary Physiology.")

When food enters the stomach, the gastric juice begins to flow, and the muscles in the walls of the stomach begin to contract so that the contents are moved about in a kind of churning motion. As this goes on, the gastric juice begins to act upon the proteid or albuminous matters contained in such foods as milk, bread, meat, and eggs, forming out of them soluble or diffusible compounds termed **peptones.** Gastric juice has no effect on the starchy portions of food, but the starchy portions that have been converted into sugar, and the peptones formed out of the proteids, are partly absorbed into the blood by the blood-vessels of the stomach. The remainder of the food forms a thick, souplike mass called **chyme.** Chyme, therefore, contains the starchy matters that have not been acted upon by the saliva, some of the proteid matters that have not been absorbed in the stomach, all the fat of the food, and any indigestible matter.

107. Digestion in the Intestines.—After a time the chyme begins to pass from the stomach into the small intestine through the pylorus. It could not so pass at first, because the opening of the pylorus was closed by a kind of ring-like muscle in its walls. When the muscle relaxes and the chyme passes into the first part of the small intestine, called the **duodenum,** it is acted upon by three fluids, the bile, the pancreatic juice, and the intestinal juice.

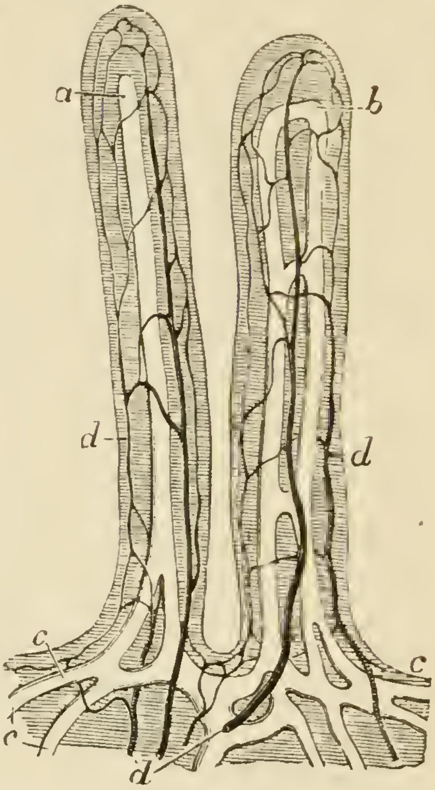
The bile is a secretion formed in the liver. The liver is the largest gland in the body, and appears as a brown fleshy mass, situated on the right side of the upper half of the abdomen beneath the lower ribs (Figs. 119 and 120). Bile is a yellowish-brown fluid secreted by the cells of the liver, and it is conducted to the **duodenum,** or first part of the small intestine, partly by the common bile-duct and partly by a duct leading from the **gall-bladder.** The gall-bladder is a small pear-shaped bag, situated behind the liver, and seen when this organ is turned up (Fig. 169). In it bile is stored, to be discharged in quantity when chyme begins to pass into the duodenum. The bile acts upon the fatty parts of the food, breaking up the fats and oils into very minute globules, and thus forming with them a creamy mass called an *emulsion*. Bile, being an alkaline fluid, neutralizes the acid gastric juice. It has also an antiseptic action, preventing the contents of the intestine from becoming putrid.

Pancreatic juice is the liquid secreted by the long narrow gland called the **pancreas**, or sweetbread, which lies beneath and partly behind the stomach, with its broad end close to the duodenum. Its duct or tube enters the duodenum along with the bile-duct from the liver.

Pancreatic juice is the most important of the digestive juices, and appears as a colourless alkaline fluid. It has an important action on all kinds of food. It finishes the work of the saliva by changing the remaining portion of the starch matters into sugar. It also acts upon proteids, changing these into diffusible peptones like the gastric juice. It also aids in turning fats into a diffusible form, partly decomposing them into a kind of soap and partly *emulsifying* them. Pancreatic juice thus completes the work of the saliva, gastric juice, and bile.

A juice secreted by some small glands in the walls of the small intestines, and called **intestinal juice**, also appears, to aid in digesting all the various kinds of food-stuffs. By the combined action, therefore, of bile, pancreatic juice, and intestinal juice, the chyme that passes into the duodenum is changed into a thin, creamy fluid called **chyle**. This chyle is constantly moved along the intestinal tube by peristaltic or worm-like contractions of the intestinal walls, for these walls, like the stomach, contain a muscular coat and, inside, a mucous membrane.

108. Absorption in the Intestines.—Though some digested materials are absorbed into the blood-vessels of the stomach, the greater portion is taken up in the intestines. To understand how this intestinal absorption is effected, we must note that the inner surface of the intestines has a velvety appearance, due to numerous hair-like projections called **villi**, the villi being like the pile of a piece of velvet. A piece of tripe shows these tiny projections, which are only about $\frac{1}{30}$ of an inch long, and so close that a sixpence would cover some hundreds.



Each of these hair-like processes, when opened and examined under a microscope, is found to contain capillary blood-vessels, derived from one or more small arteries entering the villus, the arteries being branches from the aorta. The capillaries unite to form one or more small veins, which leave the villus and unite with other small veins in the coats of the intestines. Further, in the connective tissue of each villus may be seen the *beginning* of a minute vessel called a **lacteal**, and this passes out at the base of the villus to unite with other lacteals; the whole of the lacteals of the intestines, after passing through small glands, ultimately take their contents to a tube called the **thoracic duct**. Lacteals are termed the **lymphatics** (par. 110) of the intestine.

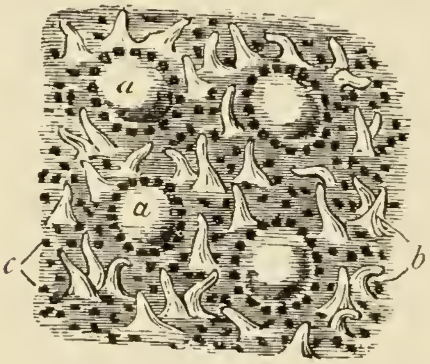


FIG. 175.—A small portion of the mucous membrane of the small intestine (magnified 12 diameters). *a*, Peyer's glands, surrounded by tubular glands; *b*, villi; *c*, opening of the tubular glands.

FIG. 176.—Two intestinal villi (magnified 100 diameters). *a*, *b*, and *c*, lacteals for absorbing fat; *d*, blood-vessels. (From Quain's "Anatomy.")

The function of the villi is to absorb the chyle or digested food materials of the intestines. They have the power of taking up through the cells forming their walls the substances of the chyle, and of passing these substances either into their capillary blood-vessels or into their lacteals. The water, dissolved salts, and peptones of the chyle are taken up by the minute blood-vessels of the villi, while the emulsified or finely divided fat passes into the lacteals, and is carried away into the intestinal lymphatic vessels to be at last passed into the blood-stream by the thoracic duct (par. 110).

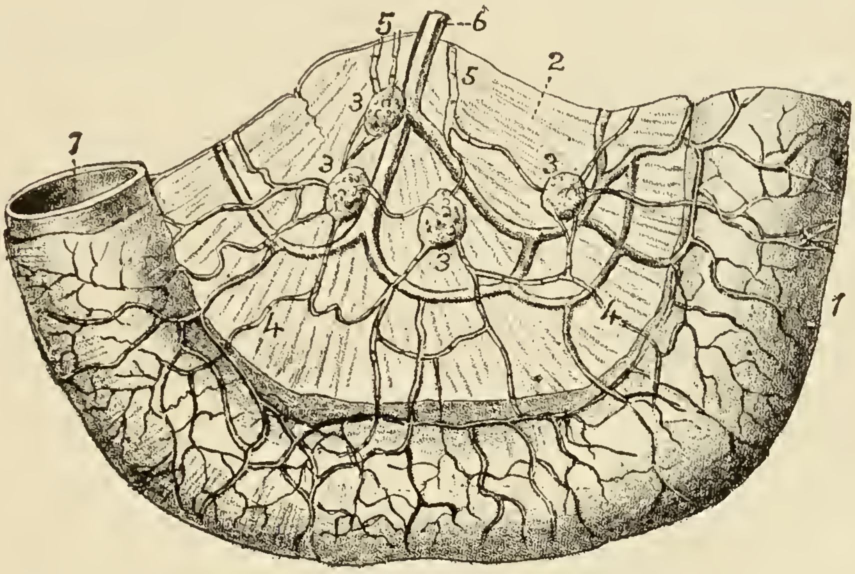


FIG. 177.—Lymphatics of the intestine. 1, portion of small intestine; 2, with layer of mesentery; 3, mesenteric lymphatic glands with lacteals (4) passing in, and (5) passing out; 6, branch of portal vein formed by smaller branches from intestine.

When the contents of the intestine have reached the lower part of the small intestine most of their nutritious portions have been absorbed, and the remaining portions with any indigestible matter pass through an opening into the dilated first part of the large intestine, called the **cæcum.** The opening leading from the ileum to the cæcum is called the **ileo-cæcal valve** (Fig. 178). A small tube at the lower end of the cæcum, four to five inches long, is termed the **vermiform appendix** (Figs. 169 and 178).

The large intestine consists of three parts after its pouched beginning, called the **cæcum.** The three parts are the ascending **colon** on the right side of the abdomen, the transverse **colon** beneath the liver and the stomach, and the descending **colon** on the left side. The descending colon passes into a straight part called the **rectum**, at the end of which is the exit termed the anus. As the unabsorbed food passes along the walls of the large intestine, owing to the contraction of its walls, water and what is left of the useful materials of the food are absorbed into the blood-vessels, and these unite with the blood-vessels from the small intestines and stomach to form the great portal vein that passes to the liver (par. 110). But the undigested portions, the indigestible matter, and some unused bile or other juice, are finally discharged from the rectum as excrement, or fæces.

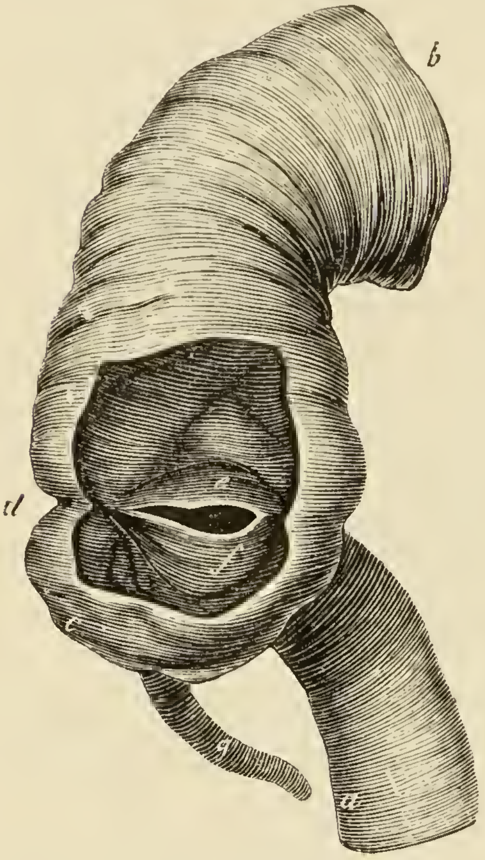


FIG. 178.—The ileo-cæcal valve. *a*, ileum; *b*, ascending colon; *c*, cæcum; *d*, junction of the cæcum and colon; *e* and *f*, loose folds of the mucous membrane, forming the ileo-cæcal valve; *g*, vermiform appendix (see Fig. 169).

109. Summary of Digestion.—Digestion (Lat. *dis*, "apart;" and *gero*, "to carry or wear") is the process of changing foodstuffs into such forms that they can be absorbed by the blood-vessels and lacteals of the alimentary canal. It begins in the mouth, and is afterwards continued into the stomach and small intestines. It is brought about by the action of ferments in the digestive juices that are supplied to the food. The table below summarizes the information respecting the four chief digestive juices. A fifth juice, called *intestinal juice*, comes from minute tubular glands in the small intestine, and probably assists in turning the starches into a soluble sugar.

Name and source.	Chemical character.	Action on food-stuffs.
Saliva from the salivary glands.	Alkaline.	Converts starch into sugar.
Gastric juice from the glands in the walls of the stomach.	Acid.	Converts proteid food-stuffs into diffusible compounds called **peptones**.
Pancreatic juice from the pancreas.	Alkaline.	Acts on all kinds of food-stuffs, converting starch into sugar, proteids into diffusible peptones, and partly decomposing and partly emulsifying fats.
Bile from the liver.	Alkaline.	Emulsifies fats by breaking them up into very fine particles.

Fluids and substances *completely* digested in the stomach are absorbed into the blood-vessels in the walls of the stomach ; the remaining portion, which is the larger part, is digested in the small intestine and absorbed either into the blood-vessels of the villi, or, in case of the fat emulsion, into the lacteals of the villi.

110. The Lymphatic System.—It has now been shown that certain parts of the digested food-stuffs are absorbed into the capillary blood-vessels of the stomach and intestines, and we know that these capillaries unite to form veins, which at last unite into one great vein called the portal vein. This portal vein passes to the liver, where it again breaks up into capillaries, in which the blood undergoes further changes, gaining *glycogen*, or liver sugar, for instance, after which it is passed into the lower vena cava, to be taken to the right side of the heart, from which it passes to the lungs. What happens to the blood in the lungs has already been explained (par. 98).

Another portion of the food-stuffs, the fats and oils, is, however, absorbed into the lacteals—minute vessels that begin in the villi—and from the vessels formed by the union of the lacteals the absorbed chyle is taken to a tube called the thoracic duct, to be poured into the blood. Now, the lacteals are often called the lymphatic vessels of the intestines, as they form part of a great system draining the tissues, called the **lymphatic system.**

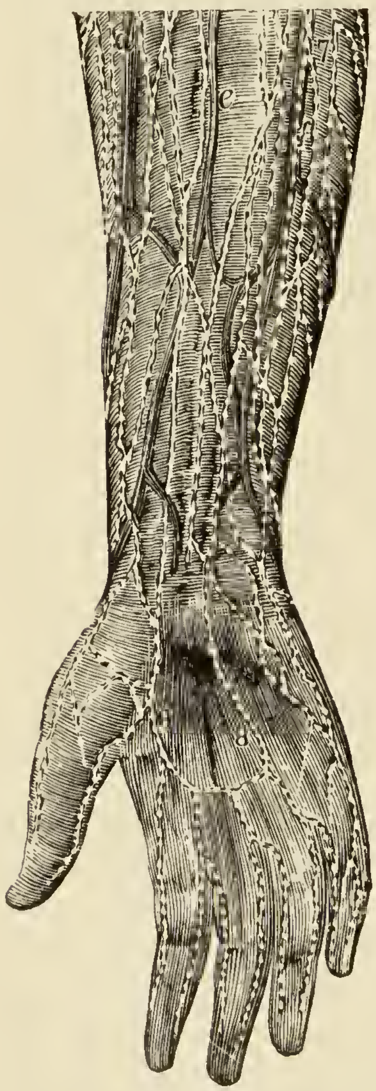


Fig. 179.—The lymphatic vessels of the hand and arm. (From Quain's "Anatomy.")

In every organ and tissue of the body there is, besides the blood-vessels, a set of minute tubes called lymphatic vessels, which *begin* in the tissues. The lymphatic vessels contain a fluid called **lymph.** To understand what lymph is, and where it comes from, we must remember that the blood is flowing through all the tissues in minute capillary tubes, and as it passes through these fine vessels some of the blood-plasma, or liquid portion, and some of the white corpuscles, ooze or pass through the delicate walls of the capillaries, so that the tissue, whether muscle or other substance, becomes bathed with the nourishing fluid thus brought to it. This fluid that has exuded into the tissue from the minute blood-vessels is lymph. It serves to nourish the cells of the tissue. All of it, however, is not used by the tissue, and the unused portion, together with some waste products of the tissues that pass into it, is gathered together into minute tubes called **lymphatics.** The lymphatics, which take their origin as channels in the tissues, convey the lymph they gather from the tissue through small lymphatic glands, where it undergoes certain changes, back into the blood. The lacteals before spoken of, and which absorb also digested fatty matters, are only the lymphatics of the intestine.

The lymphatic vessels unite to form larger and larger vessels, and in the end all join a tube called the **thoracic duct**, except the lymphatics of the right arm and those of the right side of the neck and head.

The thoracic duct is thus a common trunk vessel that receives not only the fatty chyle from the lacteals or lymphatics of the intestines, but also the lymph of all the lymphatics of the body, except those just mentioned. It is about sixteen inches long and a quarter of an inch in diameter, and extends in front of the backbone from the second lumbar vertebra to the root of the neck, where it empties its contents into the blood at the junction of two large veins called the left jugular and left subclavian veins. The lymphatic vessels from the intestines and lower parts of the body open into the dilated lower end of the thoracic duct, which is called the **receptaculum chyli** (the receptacle of the chyle). The lymphatics from the thorax join the duct higher up, and those from the left arm and the left side of the neck and head still higher. The lymphatics of the right arm and right side of the neck and head are collected into a small lymphatic duct that enters the right jugular vein.

(Lymph is a rather turbid fluid consisting of water, with proteids, salts, and other substance in solution, but it is a rather weaker solution than blood-plasma. It also contains colourless corpuscles, but no red ones. That in the lacteals during digestion is whiter in colour, and contains more nutritive matter.)

It will now be understood that the venous blood brought by the great veins to the right side of the heart not only contains certain waste matters picked up from the tissues, but that it is laden with the prepared or elaborated products of digestion. From the right side of the heart we know that

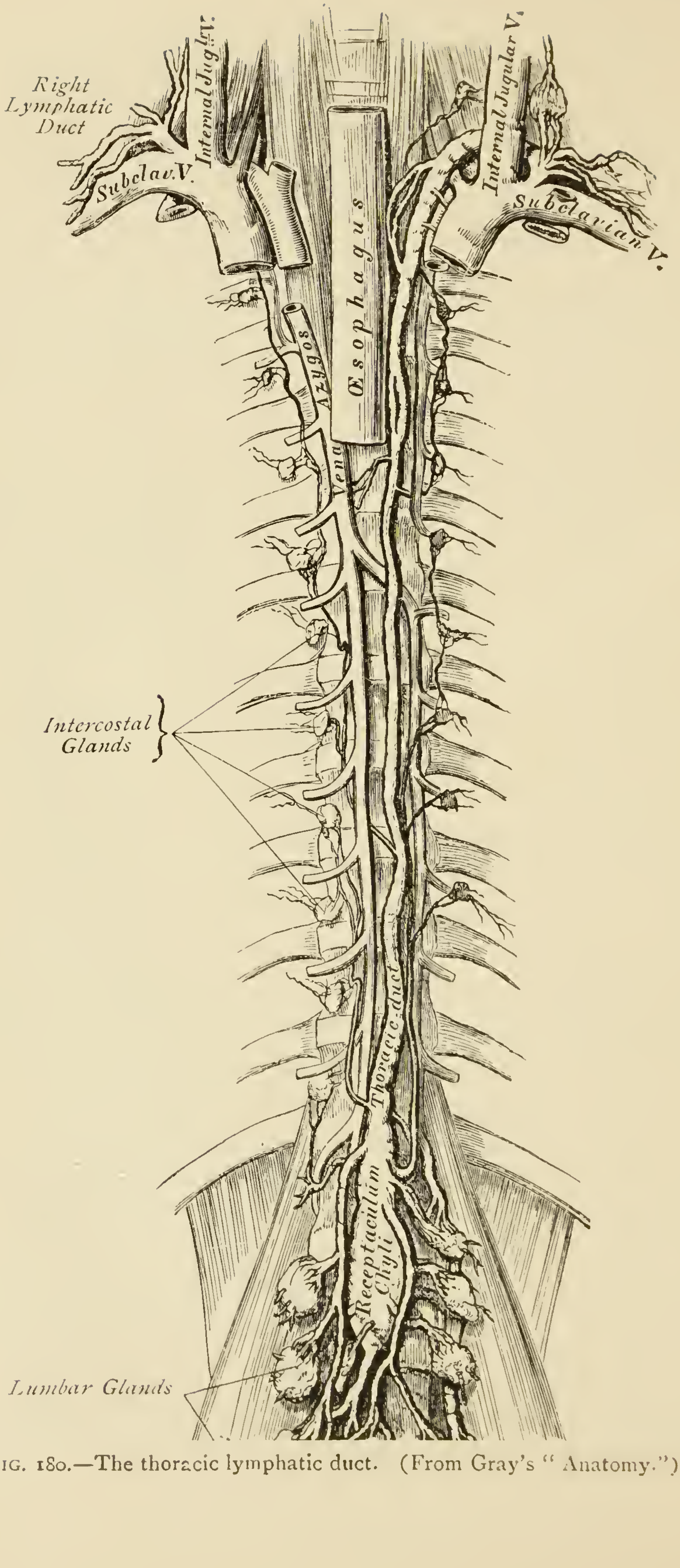


FIG. 180.—The thoracic lymphatic duct. (From Gray's "Anatomy.")

it is sent to the lungs, where it gives up one of the waste substances (carbon dioxide), and takes in a new supply of oxygen (pars. 96 and 98). From the lungs this blood passes to the left side of the heart, and is from that side forced out along the arteries, these arteries thus containing blood in a state fit for revivifying and nourishing the tissues.

Experiments.—Various simple experiments may be performed to show the action of the digestive fluids.

Make a very thin paste by boiling a small quantity of crushed starch for some time. To a small portion of this add a few drops of iodine solution. The starch becomes deep blue (par. 12). To another few drops of the starch solution in a test-tube add a teaspoonful of your own saliva, and allow the test-tube to stand for about fifteen minutes in water at the temperature of the body (98° F.). The starch solution will become thinner and clearer, and on testing a portion with iodine solution the deep blue colour will not be obtained. On adding to starch so acted on by the saliva some solution of caustic potash and two or three drops of copper sulphate solution, and then boiling, an orange-red precipitate of an oxide of copper falls down. This test indicates the presence of a reducing sugar like grape-sugar. Neither starch nor cane-sugar gives this precipitate. During a meal, therefore, we see how a portion of the starch in the food (not much, unless mastication is prolonged) becomes changed in the mouth to sugar, provided the starch has been cooked so that the cellulose covering of the starch-granules has been burst.

To show the action of gastric juice, obtain some pepsin from a chemist. Put a little into half a test-tube of water, shake well, and add a drop or two of dilute hydrochloric acid. The fluid will nearly resemble gastric juice, for on putting in a little albumen (white of egg finely divided), or particles of blood fibrin, the solid proteid will disappear in the course of an hour or so, becoming converted into a soluble peptone.

Pancreatic juice may be extracted from the pancreas of a recently killed pig by mincing the pancreas, and soaking it in water containing a small pinch of sodium carbonate for a few hours. On straining off the fluid, the liquid may be shown to convert starch into sugar, and insoluble proteid into peptone. Pancreatic juice also causes liquid fats and oils (fats are melted when taken into the stomach) to become suspended in it in minute globules, so as to form an *emulsion.* Shake a little olive oil with water in a test-tube. On standing the oil-globules soon run together again, and the two liquids separate. Shake a little olive oil and the extracted pancreatic juice together, and note the creamy emulsion obtained.

One of the common proteids is the compound called *albumen*, or *albumin.* It forms the greater part of the white of an egg, and is present in quantity in blood serum. Albumen has the remarkable property of coagulating or solidifying on being heated. This is seen every day in the cooking of eggs. On heating some blood serum the same change will be observed.

Examine a thin film of milk under the microscope, and note the tiny globules of fat of various sizes floating in a clear liquid. Place some milk in a tall vessel, and allow it to stand. The small globules of fat rise to the surface and form the cream. Remove the cream. On churning cream the small globules of fat run into a mass and form butter. The skimmed milk that is left after removing the cream contains all the proteids of the milk, and is of a higher specific gravity than fresh milk, as the lighter matter has been removed. Add to milk a little strong acetic acid (vinegar). A large part of the milk curdles or forms a coagulated mass. This curdled mass is called *casein*, and when properly treated makes cheese. The stomach contains a milk-curdling ferment called *rennin.* The small quantity of albumen in milk is mostly coagulated as a skin on boiling. On being allowed to stand, milk turns sour, owing to the change of the lactose or milk sugar into lactic acid.

CHAPTER XIX.

FOOD AND WASTE.

111. Necessity for Food.—Every living organism is continually undergoing change of substance, and the more active it is, the greater is the amount of loss of matter. The work of the animal body, both internal and external, is only carried on at the expense of the energy supplied by the oxidation of its tissues. By placing a living animal on a balance a loss of weight soon becomes manifest, and heat is constantly radiating from the body into the surrounding air. From the lungs carbon dioxide is continually being exhaled as well as water-vapour. Other sources of loss are by the kidneys (water and a nitrogenous body called urea), by the skin (water chiefly), and by the bowel. The total amount per day has been estimated to be 8½ lbs., of which 6 lbs. is water and 2½ lbs. other matter, chiefly carbon in the carbon dioxide, and nitrogen in the urea. To make good this loss of matter and energy new matter must be taken in, both to build up the substance of the tissues used up, and to restore by slow oxidation the warmth and other energy expended. Food is, in fact, needed, both for repair of the organism and as a fuel. In young and growing organisms food is also needed for growth.

The main functions of food, then, are (1) to repair the waste that is constantly going on by the oxidation of the tissues, and (2) to provide the body with energy. Food, therefore, has been defined as "*anything which when* *taken into the body is capable either of repairing its waste, or of furnishing it with material from which to produce heat or nervous and muscular work.*" To understand how this loss of matter and energy is to be made good, we must consider the nature and composition of the various substances used as food.

112. Classification of Food-stuffs.—The various substances that constitute articles of food may be classified as under:—

Water.
Organic nitrogenous compounds.
Organic non-nitrogenous compounds.
Inorganic or mineral salts.

Oxygen also may be regarded as a kind of gaseous food, taken in by respiration, and used in the tissues, mainly to produce heat, muscular movements, and other forms of energy required by the body.

The need for **water** is easy to understand when we remember that nearly two-thirds of the body weight consists of this compound, and that there is a loss of about 6 lbs. daily. Though a small portion is produced by the oxidation of the hydrogen in certain tissue compounds, the greater portion must be derived from that which one drinks, and the water in the various articles of food, for all the food-stuffs contain a considerable percentage of water. The water taken into the body serves as a tissue-builder, for the solution and conveyance of food to different parts, for the solution and removal of such waste substance as the urea in the urine. It also serves for the regulation, by evaporation from the lungs and skin, of the body heat.

113. Nitrogenous Food Substances.—The various nitrogenous food compounds are **proteids**, and all proteids are composed of carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. They are called nitrogenous, because they are the only food substances that contain nitrogen, though carbon is really the most abundant element in them. Examples of proteids are: **albumen** in white of egg, **casein** in milk, **myosin** in muscle, **fibrin** in blood, **legumen** in peas and beans, and **gluten** in bread. The proper supply of proteid substances is of great importance, for they are required to repair and renew muscular and other tissue, though also used to generate heat by combustion. The natural requirement seems to be that the food must contain sufficient nitrogen to replace that lost by the body in the urine, and the nitrogen must be in the form of a proteid, for animals cannot assimilate nitrogen in any other form. Proteids, in fact, are the only food-stuffs that can build up and repair tissue.

114. Non-nitrogenous Food Substances.—The organic compounds used as food-stuffs that do not contain nitrogen consist of carbon, hydrogen, and oxygen only, and include—

(*a*) **Carbohydrates**, compounds of carbon, hydrogen, and oxygen, in which the oxygen and hydrogen are combined in the same proportion as in water. Examples of carbohydrates are the various kinds of **starch** and **sugar.**

(*b*) **Fats and oils**, compounds of carbon, hydrogen, and oxygen, in which the oxygen of the compound is not sufficient to combine with the hydrogen to form water. Examples are: **stearin** and **palmitin** in butter, **olive oil**, etc.

Both the carbohydrates and the fats taken as food may be assimilated to renew or repair the fatty tissue, or be oxidized into carbonic acid with the production of heat or other form of energy.

115. Mineral Salts.—The mineral matter in addition to water required in the food consists of such compounds as **sodium chloride** (common salt), the phosphates of potassium, calcium, and magnesium, some carbonates, and small amounts of iron salts. These mineral compounds are useful in exercising a beneficial influence on various chemical processes of the body. Common salt is a necessity of life. One of its uses is to aid in forming the hydrochloric acid in the gastric juice of the stomach.

The phosphates of calcium and potassium are needed for the formation of bone, and iron is required in an important compound (hæmoglobin) found in the red corpuscles of the blood.

The chemical food-stuffs or compounds above enumerated are not, except in the case of water, cane-sugar, and sodium chloride, used as articles of diet in a separate and distinct state. We do not have a meal composed of myosin, casein, starch, etc.; our food materials are meat, bread, milk, etc., which contain these chemical compounds in various proportions. To ascertain the amount of such food materials required, we must know the amount of these chemical food-stuffs or *alimentary principles* in the common articles of consumption and the amount of daily loss from the body.

116. Composition of Common Articles of Food.—The following table from Waller's "Human Physiology" sets forth in an instructive way the relative amounts of food-stuffs or proximate principles contained in certain common articles of food:—

APPROXIMATE COMPOSITION OF SOME COMMON ARTICLES OF DIET.
(*Compiled chiefly from Farke's tables.*)

Articles of Food.	Alimentary principles or food constituents.				Elements.	
	Water per 100.	Proteid per 100.	Fat per 100.	Carbohydrate per 100.	Carbon per 100.	Nitrogen per 100.
Milk	86	4	4	4	7	0·6
Butter	7	1	92	—	70	0·15
Eggs	75	14	10	—	15	2
Beefsteak	70	22	5	—	15	3·3
Bread	40	8	1·5	50	28	1·25
Potatoes	75	2	—	21	10	0·3
Oatmeal	15	12	5	65	40	2
Dried peas	15	22	2	60	40	3·3
Rice	10	5	1	83	40	0·75
Cocoa powder	10	15	50	25	55	2·2
Cheese	40	35	25	—	35	5 2
Beer	89	1	—	10	5	0·15

We learn from this table that milk contains all classes of food-stuffs, and that the nitrogen and carbon are in the desirable proportion of 1 of nitrogen to 15 of carbon by weight (par. 117). Hence milk is regarded as a perfect food. The proteid in milk is in the form of casein, the fat exists in small globules which rise to the surface on standing and form cream, the carbohydrate is lactose or milk-sugar, and the salts are chiefly phosphates and chlorides of potassium and calcium. Cheese is an important product of milk, in which the element nitrogen exists in proportion to the carbon in far greater quantity than in milk, as its chief constituent is the curded casein.

Eggs approach the character of a perfect food, but the carbon element is deficient. The whole of the fat is contained in the yolk.

Of the nitrogenous articles of diet, meat is the chief, and of these beef contains the greatest proportion of proteid (myosin and globulin). Lean beef contains over 20 per cent. of proteid material, mutton 18 per cent., and pork 11 per cent. Meat also contains fatty matters (as lecithin), extractives (as kreatin and sarcolactic acid), and salts (chiefly of potassium and calcium). The flesh of poultry and fish (except eels) contains very little fat, and is therefore often eaten with bacon or butter. All these nitrogenous meats contain a quantity of carbon, for it will be remembered that proteid itself contains about 50 parts of carbon to 15 of nitrogen.

Such articles as bread and vegetables, though often spoken of as non-nitrogenous, do contain some nitrogen. Only butter, the fat of milk, and the fat of meat are in reality non-nitrogenous. Peas, indeed, contain as large a proportion of nitrogen as meat, but their nitrogen is not as easily assimilated, and they are not, therefore, as nutritive as meat. The proteid of bread is chiefly gluten, and the carbohydrate is in the form of starch. Starch, indeed, is the chief carbohydrate of all cereals.

Green vegetables contain about 90 per cent. of water, and their chief value is due to the presence of organic acids and salts.

Nearly all food-stuffs contain a small quantity of salts, and though they appear to supply little or no energy by oxidation, salts are both necessary and beneficial to the body. They are daily excreted in certain amounts, and must daily be replaced. They appear to exercise important functions in directing the metabolism of the body. Sodium and other chlorides are especially important in blood-serum ; potassium, iron, and phosphates in red corpuscles ; and calcium salts, especially the carbonate and phosphate, are necessary for bone and teeth. The most important is sodium chloride, which is taken partly in articles of diet, and partly as a condiment. One of its functions is to supply the chlorine for the hydrochloric acid of gastric juice. The greater part of the sodium chloride is, however, discharged in solution in the urine. All food-stuffs also contain a certain quantity of water (from 10 to 60 per cent.), and an additional quantity is taken in various liquids, as water is necessary to aid in dissolving the food materials and carrying them to the tissues, as well as being required to assist in removing the secretions and excretions.

117. Requisites of a Suitable Diet.—We have learnt that the loss of matter from the body is about 8½ lbs. daily—6 lbs. of water, and 2½ lbs. of other matter. The water required to repair the daily loss, less the small amount formed in the body, will be replaced by the water taken as drink, and in the articles of food; the oxygen required will be obtained from the air breathed; and the hydrogen will come with the other food. We may, therefore, confine our attention to the carbon and nitrogen. The daily loss of carbon in the carbonic dioxide given off is about 8 ozs., and the daily loss of nitrogen combined in the urea of the urine is a little more than ½ oz. The proportion of carbon to nitrogen required to replace this loss is, therefore, about 15 to 1, and our daily allowance of food should contain these elements in this proportion.

We understand, then, in the first place, that some amount of proteid or nitrogenous food is essential to life, for if an animal is fed solely on carbohydrates and other non-nitrogenous foods, it soon dies, as it continues to excrete urea in the urine when no nitrogen is being supplied, and to do this it must be consuming part of its own body-substance. But to feed an animal on proteid food substances alone is injurious, since, in order to get the requisite amount of carbon, he would have to take an excess of nitrogen, which would throw useless work on the digestive organs. From ¾ lb. of lean meat a sufficient quantity of nitrogen to repair the daily waste can be obtained, but to get a sufficient amount of carbon he would require to eat 4 lbs. of the lean meat. To eat 4 lbs. of lean meat a day for some time is impossible, as it soon becomes nauseous, and produces sickness and diarrhœa.

Again, bread contains carbon in the starch and sugar compounds in it, and nitrogen in the proteid called gluten. It has, therefore, both carbon and nitrogen, but the quantity of nitrogen is small in comparison with the carbon. Enough carbon could be obtained from a little more than 2 lbs. of bread, but we should require nearly 5 lbs. to get the necessary nitrogen.

These considerations point to the advisability of a mixture of nitrogenous and non-nitrogenous food-stuffs.

In arranging a suitable diet, therefore, we first find the quantity of a suitable proteid that will replace the amount of nitrogen lost, and supplement this with a carbohydrate or carbohydrate and fat, which will bring the quantity of carbon up to the required amount. The mineral salts (about 460 grains, or 30 grams) are supposed to be contained in the food-stuffs, while the water required is partly contained in the food and is partly taken in as water, with or without tea, coffee, etc.

The staple articles of diet, meat and bread, may be so adjusted as to supply the nitrogen and carbon in about the right proportion, *e.g.*—

	N. grams.	C. grams.
¾ lb., or 12 ozs., of lean meat (340 grains), containing .	10	37
2 lbs., or 32 ozs., of bread (906 grains), containing .	9	252
	19	289

But this is not a customary diet, as a certain proportion of fat is taken with the meat, and part of the bread is usually replaced by potatoes, rice, etc. Various combinations from the common articles may be made, of which the following is given as an example of a liberal diet :—

	N. grams.	C. grams.
16 ozs. bread, containing	5·0	125
8 ,, meat ,,	7·5	34
4 ,, fat ,,	—	84
16 ,, potatoes ,,	1·3	45
½ pint milk ,,	1·7	20
8 ozs. eggs ,,	2·0	15
4 ,, cheese ,,	3·0	20
	20·5	343

Both experience and science teach that a **mixed diet**, that is a diet made up of different articles of food, is the most suitable for health and comfort, for none of the common articles of food contain the two great classes of food-stuffs—nitrogenous and non-nitrogenous—in the right proportion. Milk comes nearest, where the proportion of nitrogenous to non-nitrogenous is as 1 to 12. It is very suitable for children, who are forming new tissue rapidly, in their growth, for all new tissue contains nitrogen. But for adults, the proportion of nitrogen is rather in excess, and for them the high percentage of water is objectionable. Mixed with oatmeal or rice, however, milk makes an admirable and cheap food, with the right proportion of nitrogen and carbon.

Of course the diet should vary with the weight, work, and age of the individual. Dr. Waller states that a man in full work requires daily 1 per cent. of his body weight in solid food and 3 per cent. in water, the 1 per cent. of solid food being made up of 0·2 per cent. of proteid, 0·15 per cent. of fat, 0·6 per cent. of carbohydrate, and 0·05 per cent. of salts. The diet for idleness would be less, as the waste of tissue and the output of energy in work and heat would be more easily balanced. In children a larger proportion of food to body weight is required, as they require food to put on flesh and fat so as to increase in size, as well as food to repair waste of tissue and supply energy.

118. The Uses of Food—Food as Fuel.—A few more words may now be added on the uses of food, since the reader will now more clearly see that there is a constant waste of matter in the body, resulting in a continual expenditure of energy in the form of mechanical work and heat. A slow oxidation is going on in the body continuously, the supply of oxygen being obtained by the lungs from the air, and carried to all parts by the blood. The food taken in, digested in the alimentary canal, absorbed into the blood, and assimilated by the tissues, is the material that is oxidized. As a result of this oxidation, waste-matter, chiefly in the shape of water, carbonic acid, and urea, are excreted or given off. The food assimilated repairs this loss of matter. As just stated, the body is constantly doing work—expending energy in the form of mechanical movement and the radiation of heat. The movement is both internal and external —movement of the heart, blood, eyes, etc., and movement of the limbs. Now, the energy of movement and of heat must be derived from some source, and the source is the oxidation of the food materials taken and absorbed either before or after they have become a part of the living substance. Food, in fact, is not only tissue-forming, but is a kind of fuel, the oxidation and breaking-up of which in all parts of the body supplies the energy of movement and heat. The more active the body is, and the more heat it loses to the surrounding air, the more rapid must be the oxidation, in order to make up the loss.

As already stated, proteids alone can repair loss of matter or waste of protoplasm, so that an animal can live on proteid alone, but not on carbohydrates or fat alone. But proteid alone is an imperfect diet, for although it can provide the energy to do mechanical work, or to provide heat, the energy is better provided by a carbohydrate or fat. Experiment shows that when a muscle contracts and does work, thereby becoming warmer, it does so mainly by means of the energy supplied by the oxidation in the muscle of carbohydrate material.

The process of oxidation by which energy is produced in the body is sometimes compared to the oxidation of coals in the furnace which supplies the heat energy to a steam-engine, but the comparison must not be pressed too far. The process in the living body is much slower, and does not go on in one place, as in the furnace, but in the blood and living tissues of all parts. Nor does it take place at so high a temperature. It must be remembered, however, that the *amount* of energy liberated by the oxidation of a given weight of any substance is just the same whether the oxidation is slow or rapid. An ounce of fat oxidized in a furnace or in the body liberates the same amount of energy. There is also another difference in the case of the body. The oxidation of the fuel in the furnace is usually complete, and the only source of energy is the engine, but the oxidation in the body often occurs in successive stages, the complex proteids, starches, and fats being gradually broken up into simpler and more stable compounds. Other kinds of chemical action besides oxidation also occur in the body, especially the formation of simpler stable compounds from the complex food principles taken in, and all these actions liberate heat energy, which may, as occasion requires, be converted into mechanical energy.

A living body is therefore continually expending energy and losing matter. By the chemical processes going on within it, especially the oxidation of tissue and absorbed food, new energy is continually being set free, and by constructive processes new protoplasm is continually being formed from the food assimilated to replace the tissues that are continually being broken down.

(On the production and regulation of the heat of the body, see Questions 6, 7, and 8 on this chapter.)

119. Exercise and Rest.—As commonly understood, exercise means the use of the voluntary muscles, especially those of the limbs and the large muscles of the trunk. Experience shows that regular daily exercise of the muscles in moderation promotes vigorous and good health. The reasons of this will appear when we consider the chief effects of muscular exercise. The vigorous use of the muscles means more active oxidation and waste of muscular tissue during the time of exercise. This leads to more rapid breathing, which means the taking in of an increased quantity of oxygen and an increased output of carbon dioxide. The heart is made to beat more vigorously in order that the blood may be sent to and from the muscular capillaries more quickly.

There is, owing to the rapid changes going on in the muscle, an increased production of heat, but this does not lead to increase of the temperature of the body, as the skin becomes more active and the evaporation of the sweat uses up the increased heat. All these effects aid in the refreshing and exhilarating of the whole body, and in promoting the digestion and assimilation of food. The effect on the muscles themselves is to increase their growth and firmness, provided that they are given sufficient rest. Witness the brawny arm of the blacksmith.

After prolonged exertion, muscles become fatigued and exhausted. Food and rest are both needed, that the wearied muscles may have time to repair and renew the tissue used up, and to get rid of the waste products of their action. During the resting period the fresh nutritive material brought by the blood is assimilated or made part of the tissue in order to replace the oxidised materials, while during the same time these oxidised materials and other waste products are carried off by the returning blood-stream and handed over to the excretory organs (lungs, kidney, and skin) for removal. Some of these waste products of muscular action, especially sarcolactic acid, seem to have poisonous effects until they have been removed.

Sleep is one form of rest that is essential, not only to the muscular system, but more especially to the nervous system; mental work demands more rest than muscular work, and sleep is the only form of complete and general rest. Other active organs require to have alternations of rest with exercise. In the case of the heart the resting periods are frequent and short, occurring between each beat. The muscles exercised in breathing also get short periods of rest between each respiration.

CHAPTER XX.

STRUCTURE AND HABITS OF FROGS AND BIRDS.

120. The frog belongs to the *vertebrate* (par. 5, p. 16) division of the animal world. Two kinds are known in this country, the common Grass Frog, and the larger, but rarer, Edible Frog. They are very similar in structure and build; but our description will apply more particularly to the common species. Both are found in the neighbourhood of ponds, streams, and ditches. Catch one, and place it under a wide-mouthed bottle for observation. The skin of this animal has in grassy tracts a yellow ground colour with dark patches, two large dark areas, one behind each eye, being specially noticeable. It changes its colour somewhat, however, with its *habitat* (the locality where it is naturally found), becoming a dusky brown where the soil is covered with decaying leaves. Its colour, in fact, affords it some protection against its enemies, birds, snakes, and some fishes (concealment by protective resemblance). Further, the skin is always moist, and possesses neither scales nor any other hard covering. The body is broad, flat, and tailless, and the broad flattened head appears to join the trunk without any noticeable neck. The frog possesses two pairs of limbs. The hind limbs are very long when compared with the fore limbs, and being very muscular also, the animal is well fitted for leaping movements. (Other leaping animals, such as the squirrel and kangaroo, have long hind limbs.) Each hind limb has five toes, and these toes are webbed together for swimming purposes. The short fore limbs have four toes only, and are without web. The frog possesses an internal skeleton, which corresponds to its body shape, and which in many respects resembles that of man and other mammals, for it is built on the same general plan.

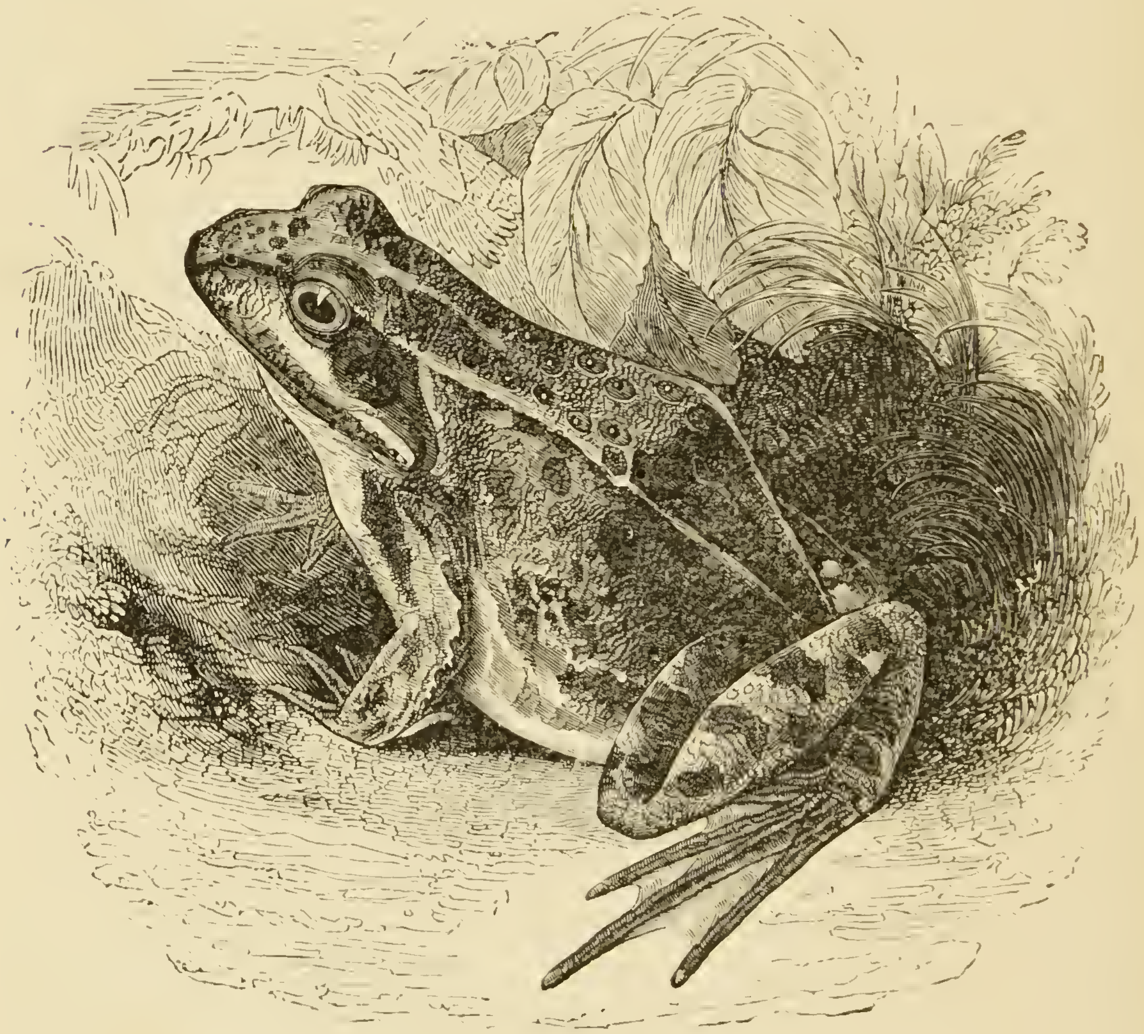


FIG. 181.—The common grass frog.

(See next par.) On land the animal pursues its prey by leaping. Squatting on its haunches, and half-supported by its arms, it watches with its protruding eyes until it sees its prey moving, and then by a sudden stretching of its long muscular hind legs, it propels itself a considerable distance. Out flies its tongue, and the insect, slug, or worm is captured. The arrangement of the tongue is well adapted for this purpose. This organ lies in the mouth. It is free behind, but attached to the lower jaw in front, so that its forked hinder part can be hurled forward. A glutinous secretion on the tongue aids in keeping the prey fast. In the upper jaw are sharp, spiky teeth, pointing backwards, and these aid in retaining the prey, which is swallowed whole. The short fore limbs serve to support the body in falling at the end of its leap. Occasionally the animal uses all its limbs in a kind of shuffling walk.

In the water a frog progresses by swimming. While swimming it folds the short fore legs alongside the body, and then by the simultaneous strokes of the two long hind legs, the five long toes of which are united by webs, it pushes itself rapidly forward. When in the water, the outer nostrils, placed near the end of its muzzle, are closed by flaps of skin. The animal can remain under water for some time.

The breathing of the frog is somewhat peculiar, for it has no separate air-tight thorax like a mammal, the lungs being in the general body cavity. Air enters through the outer nostrils directly into the mouth. The hinder nostrils are then closed by the tongue being applied to these openings, and the entrance to the gullet is also closed. The floor of the mouth is then raised, and air in the mouth is thus gulped or swallowed down the windpipe into the lungs. Expiration is chiefly effected by the elasticity of the lungs, for the frog has no ribs to be raised or lowered. Frogs also breathe to a slight extent by the absorption of oxygen through the skin.

Frogs are "cold blooded" animals, or, more accurately, *animals of varying temperature*, their temperature being that of the medium, air or water, in which they live. Mammals and birds, on the other hand, have a *constant temperature* at all seasons. A man's blood has a temperature of about 98·5° F., whatever be the temperature of the surrounding air. Hence, in the temperate zones frogs lead an active life only during the warm season. As winter approaches and their prey becomes scarce their vital activities (respiration, circulation, etc.) become slacker. At this time they bury themselves in the mud at the bottom of water, where they relapse into a state of winter sleep called **hibernation.** While hibernating, mouth and eyes are closed, and breathing by the lungs ceases, though the heart continues to beat slowly and feebly. The return of warm weather brings them forth again.

Other animals that hibernate and become torpid during winter are many snakes and such mammals as the bat, the badger, the dormouse, the hedgehog, and the bear. They do not, however, bury themselves in mud like the frog, but find secluded holes in trees, the ground, or rocks.

121. Skeleton of the Frog.—The skeleton of the frog, like that of most vertebrate animals—for example, like that of man, the cat, rabbit, and similar mammals—consists of what is called an Axial portion and an Appendicular portion. The central or axial portion consists of the **backbone, spine,** or **vertebral column** with the attached **skull.** The skull consists of the **cranium,** or brain case, and the attached **bones of the face.** The brain contained in the cranium is continuous with the spinal marrow within the backbone. The vertebral column is short, and possesses only nine vertebræ. The first vertebra, or **atlas,** possesses in front two hollows into which two processes or condyles of the occipital bone of the cranium fit. Joined to the ninth vertebra is a long bone, termed the coccyx, or **urostyle.** Each vertebra has a spinous process above and two long side processes called **transverse processes.** These must not be mistaken for ribs, for the animal has no ribs. This, besides its long hind legs, is no doubt an advantage in its leaping movements, but it also means the absence of a chest or **thorax,** such as that of the man or cat, and to a different mode of breathing as already described.

The **appendicular part** of the frog's skeleton consists of the **sternum,** the **limbs,** and the **bony arches** or **girdles** to which the limbs are attached. The sternum or breast-bone of the frog is situated on the ventral side of the body underlying the heart. It consists of bone and cartilages, and is connected above with the bones of the shoulders. The arch or girdle of bones at the shoulder contains a collar-bone or **clavicle,** and a shoulder-blade or **scapula**, as in man; but to the scapula is attached a piece of calcified cartilage of trapezoid shape, called the **suprascapula**. Behind, on each side, is a bone termed the **coracoid**, which is represented in man as a mere curved process

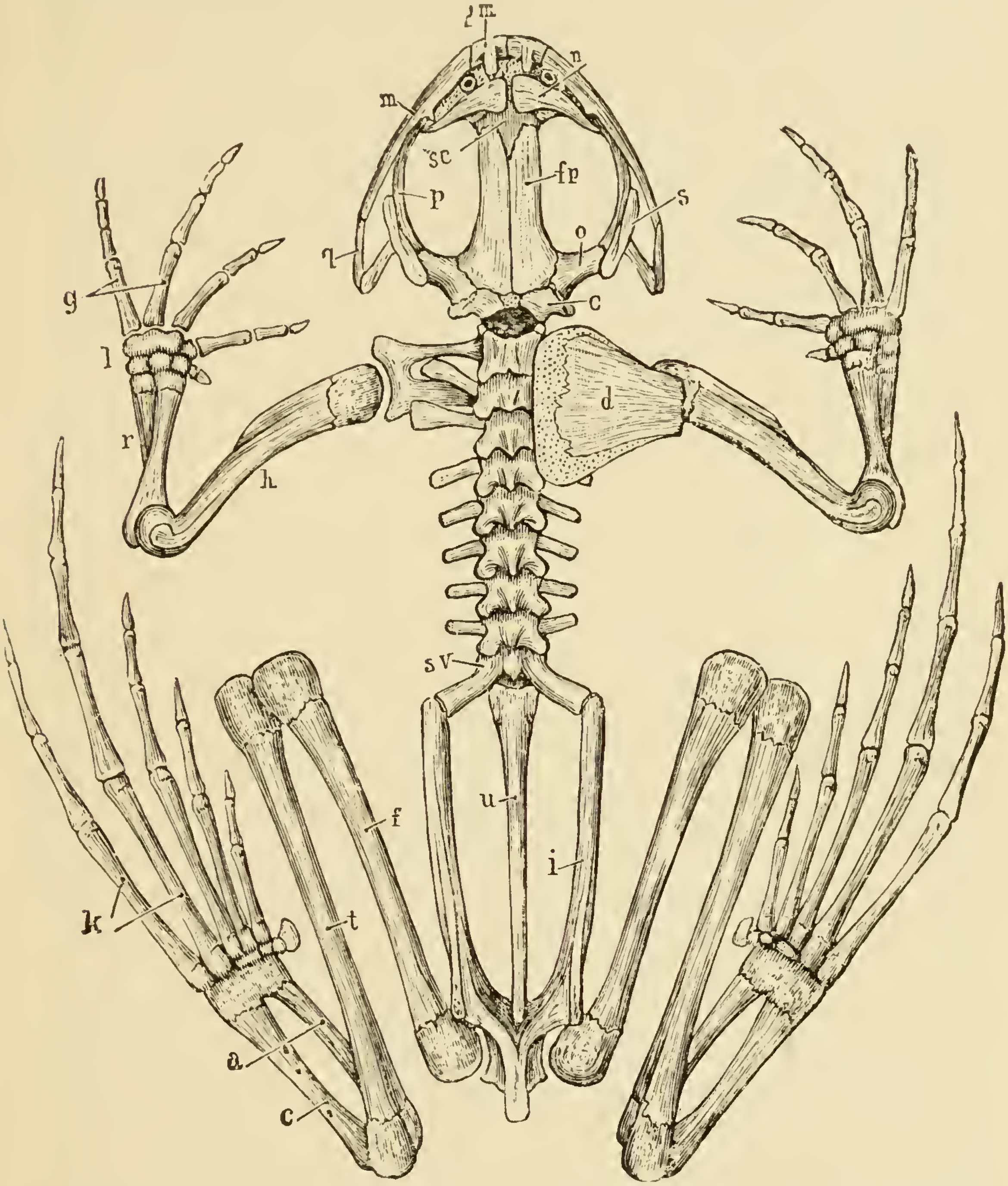


FIG. 182.—Dorsal view of frog's skeleton, with left scapula and suprascapula removed. *m*, maxilla; *n*, nasal; *se*, sphenethmoid; *p*, pterygoid; *q*, quadrato-jugal; *fp*, fronto-parietal; *s*, squamosal; *o*, pro-otic; *e*, exoccipital; *d*, suprascapula; *h*, humerus; *r*, radio-ulnar; *l*, corpal; *g*, metacarpal bones; *sv*, ninth vertebra; *u*, urostyle; *i*, ilium; *f*, femur; *t*, tibio-fibula; *a*, astragalus; *c*, calcaneum; *k*, meta-tarsal bones; *pm*, premaxilla. (Marshall.)

on the scapula. At its inner end the coracoid is connected with its fellow of the opposite side by cartilage. At the point of junction of the coracoid and scapula on each side is the **glenoid cavity** for the articulation of the fore limb. The frog's arm or fore leg is comparable with that of our own in structure. There is a short **humerus** whose rounded end nearest the spine fits into the glenoid cavity to form the shoulder-joint, a conjoined **radius** and **ulna**; six wrist or **carpal** bones (eight in man); five **metacarpal** or palm bones; and the bones of the four fingers or digits, the thumb being but rudimentary. Compare the bones of the fore limb of a frog with that of man (par. 80).

The hip-girdle or **pelvis** in the frog consists on each side of ilium, ischium, and pubes fused together. The whole pelvis resembles a two-pronged fork with a short handle. Each ilium is connected above by cartilage to the ninth vertebra. At the junction of the three pelvic or haunch-bones is a cup-shaped cavity, the acetabulum in which the head of the femur works to form the hip-joint. Like that at the shoulder, it is a ball and socket joint. The free hind limb of the frog consists of the **femur**, a **tibio-fibula** formed of a fused tibia and fibula, a **tarsus** or ankle, a **metatarsus**, and the digits or toes. Between femur and tibio-fibula is the hinge joint forming the knee. The tarsus or ankle in the frog is much elongated and consists of two long bones (**astragulus** and **calcaneum**) fused at their ends (in man there are seven tarsal bones). It is the great length of the tibio-fibula and the tarsal bones that cause the hind legs to be so long and so well fitted for leaping and swimming, when put in motion by the large muscles with which these limbs are provided. To the tarsal bones succeed the five metatarsal bones (bones of the sole of the foot). Then come the five toes, with three, three, four, five, four bones respectively, beginning with the inner toe. Compare frog's leg and foot with the human leg and foot (par. 81).

The various bones of the skeleton are bound together at the joints by means of ligaments, and as in ourselves the muscles of the animal acting under the direction of its nervous system enables the animal to execute its various movements.

122. Development of Frog.—In March and April, on the return of insect life, frogs emerge from the mud in which they have hibernated for six months. In the warm evenings the croaking of the male frog may be heard, the sound of his voice in the edible frog being strengthened by two vocal sacs protruded from slits at the angle of the mouth. Early in spring the female spawns—*i.e.* deposits her eggs. These to the number of one thousand or more are deposited in the water, and appear as tiny dark spots surrounded by a transparent jelly-like mass. Each egg, in fact, is a black spot with a jelly-like envelope that soon swells and grows larger in the water. After some hours the dark spot, which is the embryo, begins to undergo changes, and in about two weeks the warmth of the sun, transmitted through the water, has completed the hatching of the egg, and a little fish-like creature comes out. This newly hatched creature is without limbs or gills. It is a tadpole in its early stage. Such early forms may often be seen attached to pond weeds, the attachment being made by two sucking discs. Leaving the weed, it swims about by movements of its tail. A mouth now develops, and at the side of the neck feathery external gills appear, while gill clefts in the neck lead into the throat. The tadpole now breathes like a fish. It takes water in at the mouth, passes it through the gill clefts over the gills, and the gills take up the oxygen dissolved in the water. The tadpole at this stage has horny jaws on the lower side of the head, and feeds for the most part on vegetable matter in the water, though it also devours at times the flesh of a dead comrade. The external gills soon get smaller and then disappear as they are replaced by others formed internally, a fold of skin appearing on each side to cover in these internal gills. On the left side, however, the external opening remains the longer. As this fish-like tadpole grows, other changes take place in its body. Legs begin to appear and grow out slowly, first the

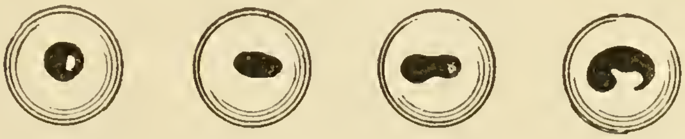


FIG. 183.—Development of the frog embryo, as observed with the unaided eye (natural size).

hinder ones and afterwards the fore legs ; the tail shortens and lungs are formed out of the internal gills, so that in the end the animal breathes by its lungs and gets its oxygen from the air. Along with these external changes, other changes also occur in its intestines, a tongue is developed and the mouth grows wider. The animal soon begins to feed on living prey, and the fish-like tadpole leaves the water as a young frog with a stumpy tail. As the tail has become useless it is gradually absorbed.

The **metamorphosis** or succession of changes from young tadpole to frog occupies from two to three weeks in warm weather, but longer when the weather is cold. A frog lives several years without further metamorphosis, except that it casts its skin for a new one periodically. The frog belongs to the class of vertebrate animals called **amphibia** (Gk. *amphi*, " both " ; *bios*, " life "), a class which includes frogs, toads, newts, and salamanders. The amphibia, properly speaking, are cold-blooded vertebrates, covered with a smooth, moist skin. In their early life they live in water and breathe by gills ; while in adult life they live on land, the gills are replaced by lungs, and the animal has then usually four limbs. In popular language, however, the term amphibia and the adjective **amphibious** is

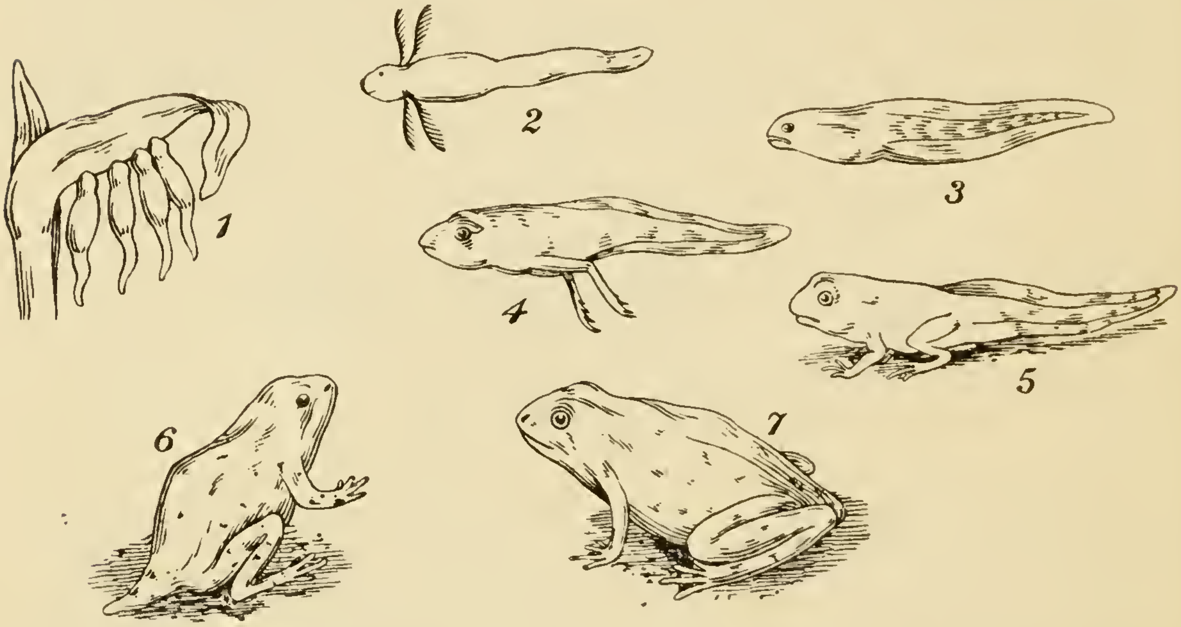


FIG. 184.—Development of frog. 1. Very young tadpoles clinging to leaf of aquatic plant. 2. Young tadpole with external gills. 3. Young tadpole with internal gills. 4. Tadpole with hind feet partly developed. 5. Tadpole or young frog with both sets of limbs. 6. Young frog with stumpy tail. 7. Young frog complete.

applied to any animal that spends its time partly on land and partly in water, though unable to breathe under water, such as otters, beavers, seals, etc.

Frog spawn is readily obtainable in spring, and tadpoles can be reared in a small aquarium, so that the student may easily observe most of the changes described.

123. Birds.—Birds may be described as warm-blooded, feathered, egg-laying vertebrate animals. They breathe by lungs, and have the fore limbs modified into organs of flight. A bird being a vertebrate animal is built on the same general plan as the frog, a quadruped, or man; that is, it has the same bones in the same relative positions, but through fusion together of some and change of form in others it has certain peculiarities of skeleton structure that adapt it for flying through the air. As birds live under very varying conditions, special bodily arrangements are also necessary. Nearly all, however, possess the faculty of flight. Hence the most important structural adaptation is found in the modification of the shoulder girdle and fore limb, for the fore limbs of the bird are intended, when supplied with feathers, to raise the body into the air and to carry it along, while the fore limbs in quadrupeds are used in locomotion on the ground, and in man they are developed into a hand. The whole trunk of a bird is compact and firm, while the bones in particular are specially suited to an animal that must raise itself from the ground to move through the air. These and other structural adaptations will appear after a careful study of the skeleton. Fig. 185 will enable the student to follow a description of the bony framework of a flying bird, but the reader must also see a few actual mounted skeletons in a museum or elsewhere. In the living bird the various bones are connected together at the joints by ligaments (par. 82); but these have disappeared in the dry skeleton, and the bones are wired together at the joints.

124. Skeleton of Bird.—The skeleton of a bird may be divided into an Axial portion and an Appendicular portion, like that of the frog, but the great amount of fusion of bones is characteristic of a bird's skeleton. The axial portion of the skeleton consists of the **skull** and the **vertebral column.** The skull is light and consists of a number of bones, many of which are fused together. The cranial part forms a rounded brain case. The upper and lower mamillary bones are movable, elongated, and covered with a horny case to form the **bill.** The lower jaw or mandible does not unite directly to the upper, but is connected to the latter by a quadrate bone. The bill is adapted in size, shape, and hardness to the kind of food and to the manner of obtaining it. It performs, to a large extent, the functions of a hand. Thus it is strong and hook-shaped in birds that tear their prey, short and conical in grain-eaters, broad and flat in ducks and geese. The skull is connected with the spinal column by a single condyle that articulates with the atlas or first vertebra, an arrangement which together with the odontoid peg of the axis or second vertebra, and the movable neck allows the bird to turn its head so as to look backwards. The vertebræ of the neck, bound together by ligaments, are movable, and vary in number from ten to twenty, while the neck of mammals nearly always contains seven vertebræ. The flexible neck usually bears some proportion to the length of the legs, for the bird must be able not only to look round, but also to reach the ground with its beak. The five dorsal vertebræ are fused together, while the fourteen or fifteen lumbar and sacral vertebræ unite to form one rigid bone, the "sacrum." This enters into immovable connection with the bones forming the pelvis or hip-girdle, being wedged in between the pelvic bones of each side. Behind the rigid vertebræ of the trunk are a few movable vertebræ in the tail, and these movable tail vertebræ end in a large plough-share bone which bears the long steering feathers of the tail.

The appendicular part of the skeleton consists of **sternum, ribs,** the **limbs** and their **arches.** The sternum of birds is a large, broad, thin plate of bone which covers the thorax, and in some birds extends over part of the abdomen as well. In front it has an obtuse process, while other processes occur behind and

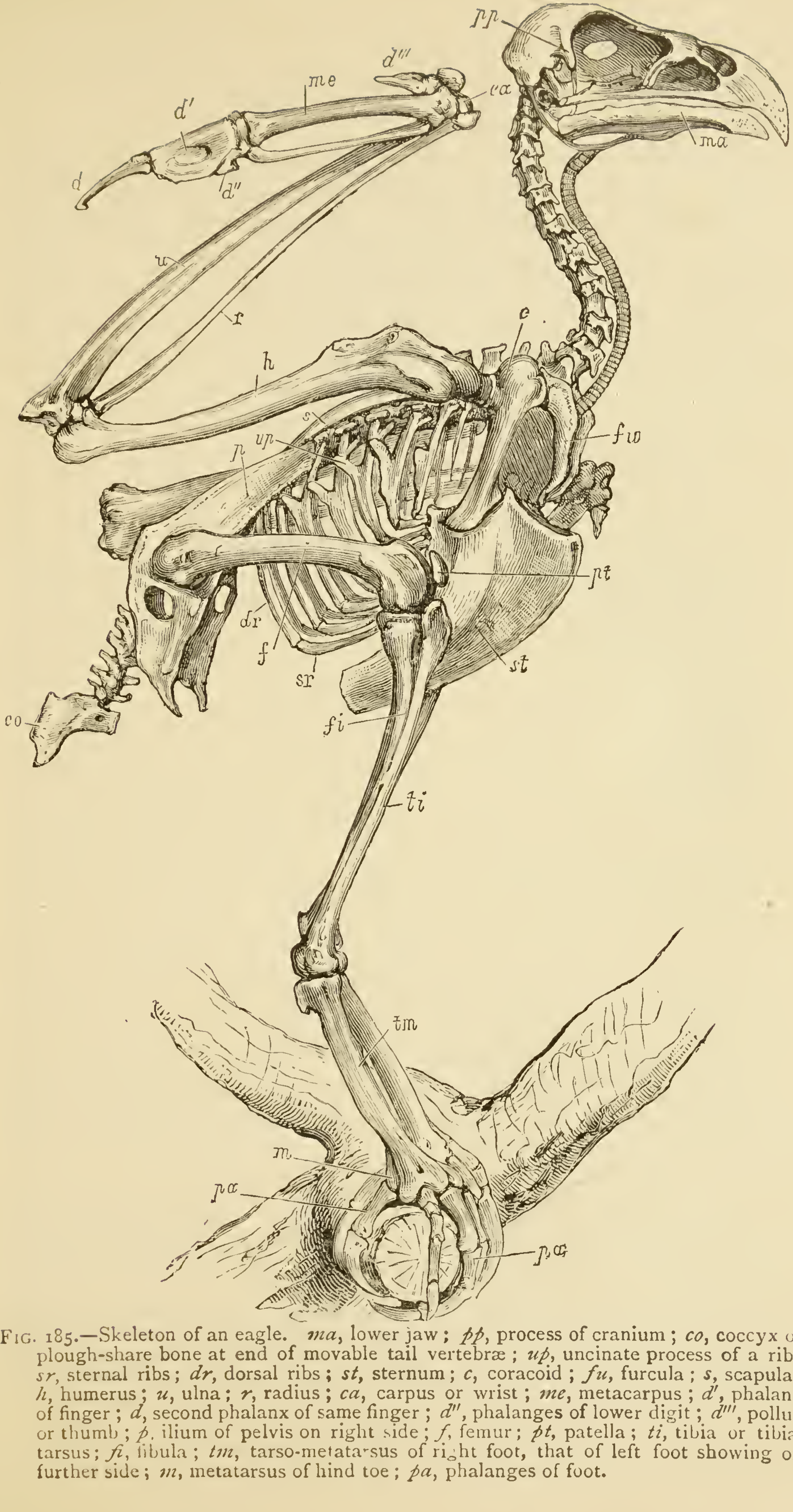


Fig. 185.—Skeleton of an eagle. *ma*, lower jaw; *pp*, process of cranium; *co*, coccyx or plough-share bone at end of movable tail vertebræ; *up*, uncinate process of a rib; *sr*, sternal ribs; *dr*, dorsal ribs; *st*, sternum; *c*, coracoid; *fu*, furcula; *s*, scapula; *h*, humerus; *u*, ulna; *r*, radius; *ca*, carpus or wrist; *me*, metacarpus; *d′*, phalanx of finger; *d*, second phalanx of same finger; *d″*, phalanges of lower digit; *d‴*, pollux or thumb; *p*, ilium of pelvis on right side; *f*, femur; *pt*, patella; *ti*, tibia or tibia-tarsus; *fi*, fibula; *tm*, tarso-metatarsus of right foot, that of left foot showing on further side; *m*, metatarsus of hind toe; *pa*, phalanges of foot.

at the sides. Further, the sternum in all flying birds bears a projecting ridge or keel along the middle, and to this keel and the body of the breast-bone large and strong flying muscles are attached. The sides of the thorax are bounded by ribs, which vary in number, according to the class of bird, from six to ten pairs. Some of the ribs are free at their lower end, but most pass from the vertebræ to be articulated with the sternum. Each of these complete ribs (five pairs in the pigeon) possesses a joint at a point nearer the sternum, and the two parts are spoken of as **dorsal ribs** and **sternal ribs** respectively. Some of the ribs also possess near their upper end a process, the **uncinate** process, which passes upwards and backwards over the rib behind, to which it is bound down by ligament. Those processes thus serve to strengthen the thorax. The shoulder girdle consists of a **scapula,** a **coracoid** and a **clavicle** on each side. The scapula, or shoulder-blade, is a long blade-like bone running backwards over the ribs and alongside the backbone, and attached to this bone by muscles. It unites in front with the upper end of a rod-like bone called the coracoid. This bone does not exist in man and other mammals, but is represented by a curved process of the scapula. Each coracoid bone articulates at its lower end with the upper angle of the sternum. From the upper end of each coracoid a slender clavicle passes downwards and forwards, but each clavicle unites to meet its fellow in front of the breast, forming with the uniting plate a compound bone called the **furcula.** The popular name for this bone is the "merry thought" or "wish-bone." A ligament passes from the uniting plate of the furcula to the top of the sternum. The clavicle and coracoid have an outward slope and buttress each other, and the whole arrangement of the shoulder girdle results in a firm pivot being provided on which the wing can move (Fig. 186).

The fore limb or wing of a bird, like our arm, consists of four parts, the upper arm, the fore arm, the wrist, and the hand, and the same bones may be recognized, though reduced in number owing to fusion, and often of different form ; for the limb is modified to suit its function as an organ of flight. The skeleton of the upper arm contains a short and strong **humerus,** the upper end of which fits into a glenoid socket formed at the shoulder by the coracoid and scapula. At this ball and socket joint there is great freedom of movement. The lower end of the humerus articulates with the two distinct bones forming the fore arm, a slender **radius** and a stout **ulna** to form the elbow-joint; and this hinge-joint allows of movement in one plane, but no turning of the radius over the ulna (par. 80). These are followed by the **carpal** or wrist bones, but in the bird there are only two carpal bones, and these are so fixed that the hand part can turn but little at the wrist. The other carpal bones are fused with the metacarpals—that is, to the bones that correspond to those in the palm of the hand. There are only three metacarpals, and these are fused together at the end nearest the body. The first is very short, and bears the thumb or **pollex** with one **phalanx**, *d'''*. Far away from the thumb, at the end of the two long metacarpal bones which are united at their ends, are two broad fingers or digits firmly fused to one another, one possessing two phalanges (*d* and *d'* in Fig. 185) and the other possessing one phalanx, *d''*. We thus see that a bird's fore limb is of remarkable length, permits hinge-like movements for folding and unfolding the wing, is rigid or flexible as required, and possesses certain broad surfaces for the attachment of the flying feathers. When at rest the wing folds so as to lie against the trunk in the form of a Z. The **pelvis** or hip-girdle of the bird is long, and consists on each side of an **ilium** fused before and behind the hip-joint to some of the posterior vertebræ, an **ischium** running backwards, and a third part, the **pubis**, also running backwards, though these bones being all fused together are difficult to recognize. At its anterior end the pelvis roofs over part of the spine. All these three bones help to form the **acetabulum** or socket for the thigh bone. In a dried skeleton this socket

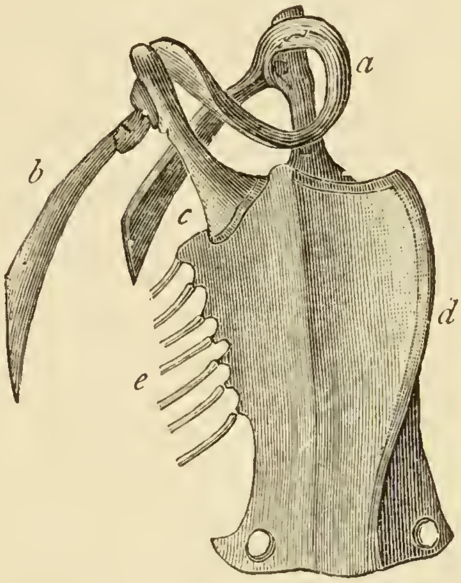


FIG. 186.—Part of sternum and the shoulder girdle of falcon. *a*, furcula formed by the union of the two clavicles; *b*, scapula; *c*, coracoid; *d*, keel of sternum; *e*, ribs.

appears to have no bottom, but in the living bird the bottom was formed of membrane, which has disappeared. The free hind limb or leg of the bird is made up of a short stout femur or thigh-bone, which is always hidden in flesh at the side of the body, followed by the two bones of the lower leg (the leg proper), the **tibia**, and a very slender **fibula**, the latter being imperfect and fused to the tibia. At the knee is a **patella** or knee-cap. There are no separate tarsal or ankle-bones. The lower end of the tibia is made up of the first bones of the tarsus or ankle, and hence the tibia is properly called the **tibia-tarsus**; while the lower part or the shank of a bird is made up of the remaining tarsal bones fused to the metatarsals (the metatarsals in man form the sole of the foot) to form another compound bone called the **tarso-metatarsus**. The hip-joints of a bird are thus wide apart and high up on the body; the knees are just under the body, hidden among the feathers, and the heel is high above the ground. Below the shank, or long-fused tarso-metatarsus, which is really a part of the foot placed upright, are the toes, on which the bird stands. (Compare with cat, which also walks on its toes; and with man, who walks on the soles of his feet.) Most birds have four toes or digits. Of the four toes, the first, which is directed backwards, has two joints or phalanges; the second or inner, three; the middle toe has four, and the outermost five phalanges. The terminal joint of each toe is provided with a claw, which differs from a nail only by the hard epidermis growing on all sides instead of on one only. The great differences in the length of legs in birds are mainly due to variations in the length of the shank and tibio-tarsus bone. The shape and arrangement of the toes vary with the habits and special activities of the bird. Birds of prey (eagles, falcons, and vultures) have stout grasping feet, with sharply hooked claws or talons; in scraping birds the toes are short, and have short blunt claws; climbers, like woodpeckers and parrots, have two toes turned backwards and two forwards, and the claws are curved and sharply pointed; swimmers, like ducks and geese, have the three front toes webbed together (pelicans have the four toes webbed together); waders, like storks and herons, have very long legs, owing to a specially long tarso-metatarsus, and correspondingly long necks, with long beaks, as they have to find a large part of their food in ponds and streams. As already stated, the whole skeleton in the bird is extremely light, though the bones are dense and hard. The skeleton of a pigeon does not weigh one quarter of an ounce. This is due to the fact that in most birds the larger bones are hollow, either completely hollow or, in large birds, crossed by a delicate network of bone, and contain air. The larger long bones have, therefore, a tubular structure. In reptiles, amphibia, and mammals the bones are heavier, as they are either solid or filled with marrow.

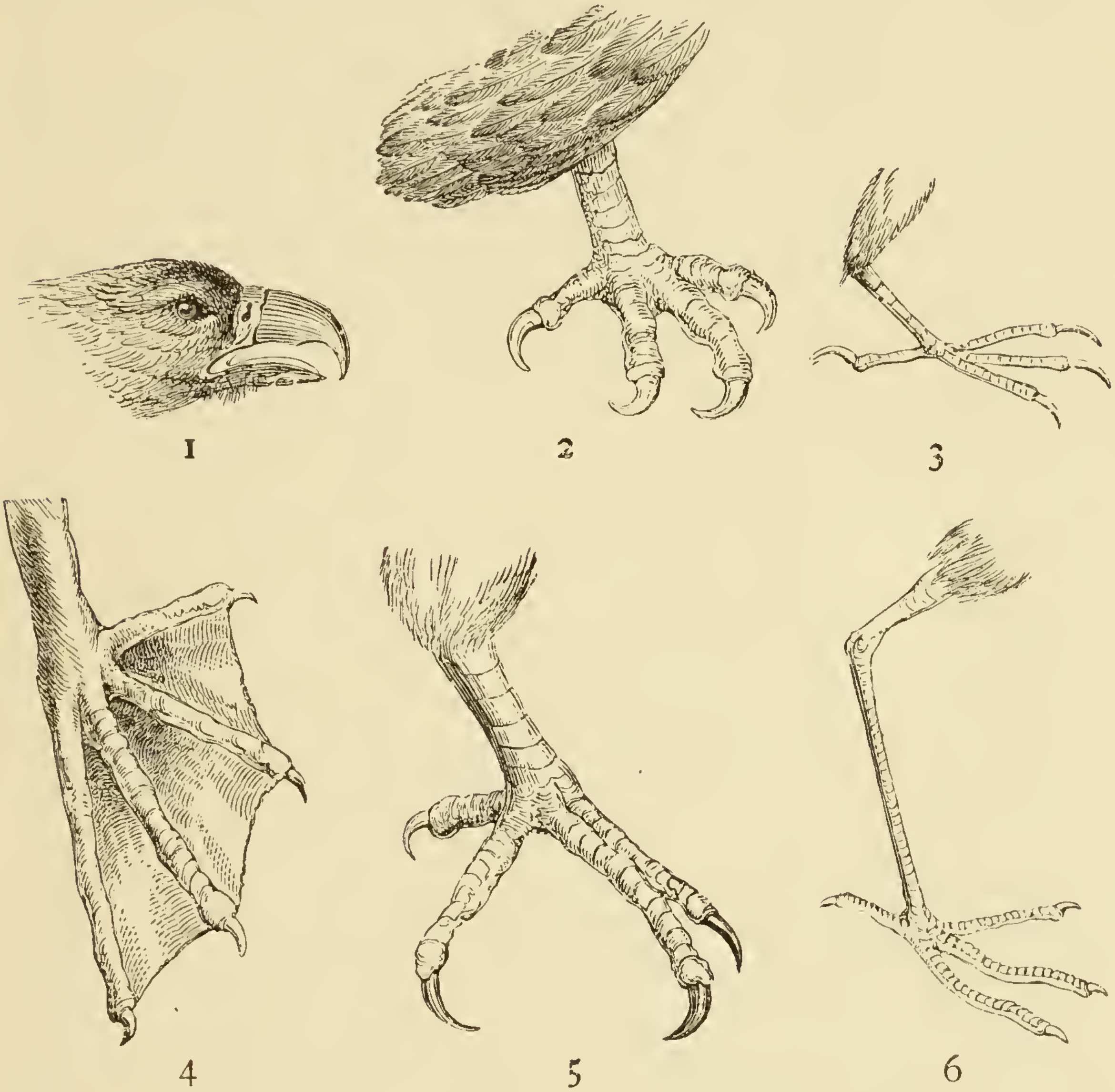


Fig. 187.—1. Head of eagle. 2. Part of foot of eagle, showing the claws. 3. Foot of perching bird. 4. Foot of pelican. 5. Foot of woodpecker (climber). 6. Foot of wading bird.

The student should compare corresponding parts of the skeleton of man, the cat or rabbit, the frog and a bird, especially the skeleton parts of the limbs. Man walks on his soles, with the heel on the ground (**plantigrade**) (Lat. *planta*, "the sole"); the cat tribe walk on the toes, **digitigrade**. All birds walk on the toes. The rabbit walks for the most part on its toes, but allows the whole sole to touch the ground.

125. Structural Adaptation of the Bird for Flight.—The structure of the skeleton shows that a bird is adapted for flight through the air. In the first place, the form of the skeleton results in the body being doubly pointed, or spindle-shaped, and it thereby cleaves the air with the least resistance, while the feathers all point backwards, and are pressed close against the body as the bird passes through the air. In the next place, the bones combine in a remarkable degree strength and lightness. The vertebræ of the trunk are firmly bound together, and the ribs are joined to the large keeled sternum by bony sternal segments, not by cartilaginous segments as in man and quadrupeds. Hence the skeleton of the trunk is firm and rigid, like the keel of a ship. Flying is effected by the active movements of the wings that are supplied with flight feathers, and the connection of the wing bones with the shoulder girdle is very strong, for the shoulder joint on each side is placed at the meeting of three bones, scapula, coracoid and clavicle, and these three bones form a firm pivot for the wing. If the muscles that move the wings were attached to bones moving freely on one another their action would be weakened. The bones of the fore-limb are so modified that the whole limb is long, especially the "hand" part—metacarpus and consolidated phalanges—to which some of the chief flight feathers are attached. Its few fingers are bound together in a fold of skin. Moreover, the bones of the wing are capable of but little movement beyond the hinge movements at the elbow and wrist, and this gives firmness to the downstroke of the wing. The head is small and light, while the movement of the skull on one condyle and the numerous vertebræ of the neck enable the bird to turn its head easily and to reach all parts of the body with its beak. Apart from the firm and rigid skeleton of the trunk, and the formation of the bones of the arm, many bones in the flying birds, as the bones of the skull, the coracoid, the breast bone, the humerus, etc., are filled with warm air, thus increasing the buoyancy of the body. In some of the larger bones, as the humerus, a distinct hole may be found at one end, which is connected with air sacs from the lungs.

The muscular system also shows adaptations to an aërial life. The great muscles which effect the downward stroke of the wings are situated on the large keeled breast-bone and tendons; from them pass to the humerus. The muscle which raises the wing is also situated beneath the breast-bone. This is the reason why there is so much meat on the breast of a flying bird. Compare the quantity on the breast of a wild duck and on the breast of a tame duck. The position of this great quantity of muscle on the breast tends to keep the centre of gravity of the body low, and thus prevents overturning in the air. In man the muscles which raise and drawback the arm are on the dorsal surface, and those which lower it and move it forwards on the breast. It would be a bad arrangement if a bird had a mass of flesh on its back.

Birds that are poor flyers, like the domestic fowl, have but poorly developed wings, only a small keel on the breast-bone, and the breast muscles are small. This is still more the case with birds, like the ostrich, that do not fly at all.

How the feathers are constructed and how they aid in flight will be seen in succeeding paragraphs.

A peculiarity in the leg of the perching birds is worthy of special mention. The perchers, or **passerines**, include the largest number of birds—all our common songsters, and all the birds that live in trees. Their feet are adapted for grasping slender supports, and they all have three toes in front and one behind. They sleep on twigs and boughs, and in this position are safe from nocturnal enemies. Why do they not fall off their perch in sleep? As pointed out in par. 86, the bones are moved on one another at the joints by the contraction of muscles, and muscles are attached to bones by tendons (par. 84). In the leg of the bird are several muscles with long tendons. One of these muscles, *a* (Fig. 188), springs from the pelvis, and forms part of the thigh; it gives off a tendon that passes over the knee-joint, *b*. The tendon then passes backward through a ligament, *b′*, so as to cross the heel-joint, *c*, behind. From the heel-joint it passes along the tarso-metatarsus of the foot, and divides at *d* in branches that pass to the toes. Contraction of the muscle *a*, therefore, leads to a pull on the long tendon that passes from it to the toes, and the stretched tendon thus bends the toes. This bending of the toes also results without the contraction of the muscle whenever the leg is bent on the thigh at the knee, and at the ankle as in perching (Fig. 188). In a roosting bird, the bending of the leg at the knee and ankle results without effort from the mere weight of its own body, and this bending causes the toes to grip the perch. The sleeping bird thus maintains its hold unconsciously, and by laying its head over its back during sleep it brings the centre of gravity of its body over its legs and so increases the stability of its position.

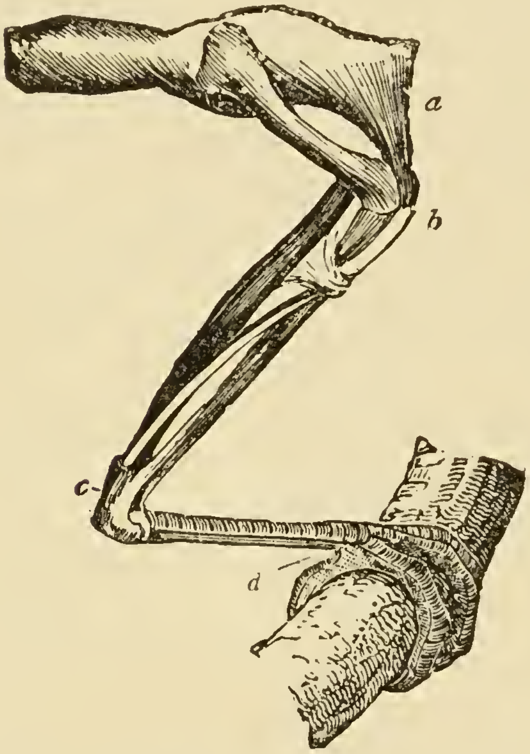


FIG. 188.—Leg of bird perching, with skin removed to show, *a*, muscle attached to pelvis ; *b*, tendon of muscle passing over knee-joint in front and then through ligament, *b′*, to back of leg and across heel-joint at *c* behind, down tarsus-metatarsus to *d*, where it divides and passes to the toes.

In walking on its two legs a bird carries its body at an upward inclination. The high position of the hip-joints, their distance apart, and the position of the centre of gravity of the body low down in the trunk, enables the bird when on its feet to keep its body in equilibrium. The spreading toes increase the surface of support.

126. The Common Pigeon.—A common pigeon—a **blue rock**, for example—will now serve as a suitable type of the flying bird.[1] Watch a group of pigeons as they walk about, and notice the form and habits of the bird. They feed on all kinds of grain, gathered in the fields when these are not supplied by man. Unlike other birds, they keep the beak in the water when drinking until thirst is quenched. Visit the dovecote. Pigeons live in pairs. The female lays two white eggs at a sitting. The young are naked and helpless when hatched, and must for some time be kept warm and fed by the parents. Neither are they able at first to digest hard seed grains. Hence they are fed for the first three weeks with milky, crumbly material, prepared in the crop of the parents. For a short time after this they are fed with softened grain from the parents' crops. Contrast with hen, which lays several eggs at a sitting, while chickens are covered with down, and can run about as soon as hatched. Obtain one or two recently killed pigeons, and examine one with the feathers on and a plucked one. Note the head and the convex horny beak; the nostrils at the base of a white patch of swollen skin, called the **cere**; the openings into the internal ears among feathers a little below and behind the eyes. The eyes are constructed on the same plan as those of man, but they possess, in addition, a third transparent eyelid, called the **nictitating** (*winking*) **membrane.** It arises from the inner angle of the eye, and can be spread over the front surface like a transparent veil, and thus acts as a screen against too strong a light. Observe the arrangement of the feathers, and the position of the largest ones. As you pluck a bird, note the large pits, or sockets, from which the large feathers come. Grasp the crop in the neck, and note the corn it will probably contain. Feel along the prominent sharp keel of the breast-bone, and notice the mass of flesh (muscle) on each side of the keel. Examine in both a feathered and a plucked specimen the hind limb. Beneath the skin are the muscles (flesh) which surround the bones. Find the hip-joints high up on each side near the back of the bird. Notice the short thigh running forwards at the side of the body, and feel the femur through the flesh in which it is embedded. Find the knee-joint on each side of the body hidden among feathers. Pass along the tibia, or rather tibio-tarsus, to the heel (which must not be mistaken for the knee), and note that the feathers cease here, for the foot from the heel downwards, including the toes, are covered with red scales. Now proceed to the wing. Open it out. Notice the extensible fold of skin, widest at the "elbow," helping to unite the upper arm and the fore-arm, and another fold reaching from the upper arm to the trunk. Starting from the shoulder-joint, feel through the skin and flesh in the plucked bird for the bones in the wing, the bones corresponding to the bones in our upper arm, fore-arm, wrist, and hand, remembering that there are only two small carpal, or wrist-bones, and that the hand part has been greatly modified, and consists of two long metacarpal bones, at the ends of which are two fingers in a fold of skin (see par. 125, and Fig. 185). A small thumb bearing a tuft of feathers lies much further back than the fingers, at the upper side of the wrist-joint. Hence the joint at the front angle of wing corresponds to the wrist-joint, but the hand is bent back on the fore-arm when the wing is folded, and then arm, fore-arm, and hand lie alongside each other in a Z form, a position our fore limb cannot assume. Inside the trunk of a bird is a cavity, in which lie the lungs, the air sacs, the heart, the stomach, intestines, liver, etc. The structure of a feather, and the arrangement of the feathers of the wing will now be described.

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[1] There are four kinds of wild pigeons in England—the ring-dove or wood-pigeon, the stock-dove, the rock-dove, and the turtle-dove (a summer visitor only). All varieties of the domestic pigeon have descended from the rock-dove, a bird which builds in the crevices of rocks along the sea-coast.

127. Feathers.—Birds are clothed with feathers of various form that serve admirably for keeping in the heat of the body (see par. 118 and Quest. 8, Chap. XVI.). The feathers entangle among the barbs a good deal of air, and thus enclose a warm layer of air next the body. This enclosed air aids in preventing the escape of the heat produced in the body, for air is a bad conductor. Those of the pigeon or other common bird may be conveniently examined. Feathers grow in a little pit or sac of the skin, easily noticed on plucking a bird, and with this sac are often associated strips of muscular tissue that serve to erect the feathers. They consist of a very light horny substance, and are filled with air in the thicker parts. An ordinary feather exhibits two chief parts, a central axis and a vane of barbs on each side. The axis is divided into a bare, hollow, lower portion called the *quill*, and a more solid upper barb-bearing portion called the *shaft*. The quill portion is semi-transparent, and has at its lower end a hole, in which a little fleshy papilla is inserted, and through which, in the growing feather, a small blood-vessel passes to supply nutrient material. In the perfect feather a dry pith remains in the quill part, but in a young growing feather blood will be found in the quill portion. Although the skin of the bird is completely protected by the overlying feathers, feathers do not grow in all parts, but in definite tracts separated by featherless spaces. The main covering feathers are spoken of as "contour feathers," or **pennae**. The contour feathers are named after the parts of the body they cover (neck feathers, breast feathers, etc.). Among and below these are often softer "down feathers," forming an under coat (the pigeon has no down feathers). In addition to these are simpler and smaller thread-like feathers left in the skin after

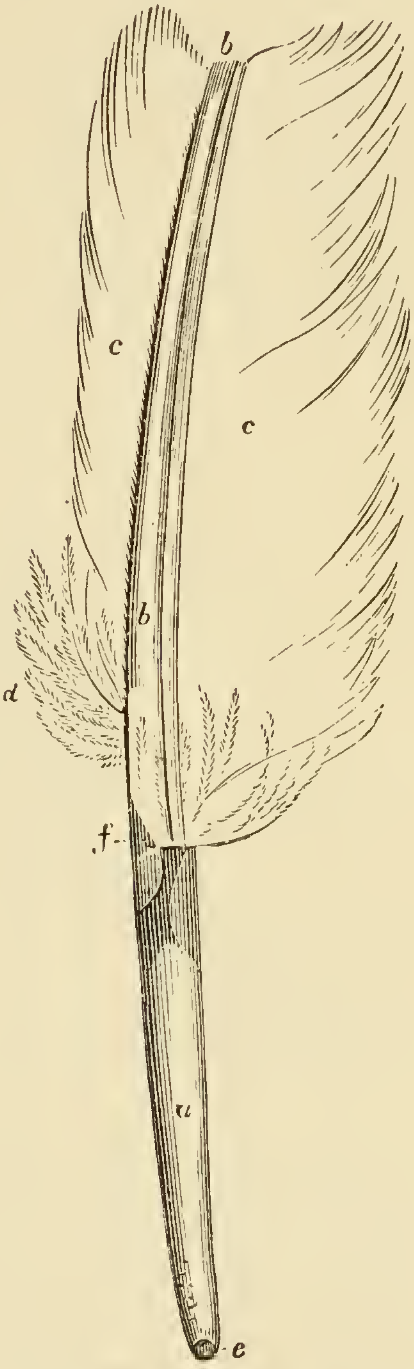

FIG. 189. — Contour feather. *a*, quill part; *b*, shaft; *c c*, vanes; *d*, barbs with barbules; *e*, hole at lower end of quill; *f*, hole at upper end of quill.

plucking. These have a very thin stem and a rudimentary vane at the apex: they are called **filoplumes**. The most conspicuous feathers are the large flight feathers of the wing (**remiges**), and the large steering feathers of the tail (**rectrices**). As already stated, the large feathers exhibit a quill with a hole at its lower end, and a shaft with a flat portion on each side, called the blade or vane. One vane in the flying feathers of the wing is wider than the other. Each vane consists of a large number of separate lathe-like parts springing from the shaft, and called **barbs**. They run obliquely upwards and parallel to one another so as to form a continuous sheet. The barbs adhere together and some little force is required to separate them. The cause of this will become clear if two or three barbs be removed and examined with a good magnifying glass, or, better, under a low power of the microscope. Each barb will be seen to give off on each side smaller barbs or **barbules**. The anterior barbules, or those nearer the tip of the feather, bear some tiny hooks; the posterior barbules, or those nearer the quill, are without hooks. When the vane is perfect the little hooks on the anterior barbules of one barb hitch over and interlock with the posterior barbules of the preceding barb, so that the vane forms a continuous sheet (see Figs. 190, 192).

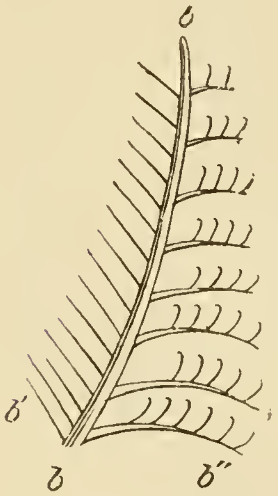

Fig. 190.—Portion of barb magnified; *b b*, barb; *b′*, barbules without hooklets; *b″*, barbules with hooklets.

The fluffy down-feathers and filoplumes have no hooks on the barbules. It is interesting to note here that ostrich feathers have no hooks on the barbules, hence the barbs do not cling together. Feathers usually last but one year, for, as a rule, at the beginning of autumn, the feathers are gradually shed and replaced by new ones. The process is called **moulting**. To prevent moisture from adhering to the feathers, a result which would not only increase the body weight but would also lessen the effectiveness of the feathers as an agent for conserving the body heat, an oily fluid is frequently applied to them by the bird. This oily fluid is supplied by a special oil gland situated at the root of the tail above the caudal vertebræ. The length and mobility of the neck enables the bird to reach this gland with its beak, and it then uses this organ as a comb and brush to straighten and lubricate its feathers. The process is known as "preening" the feathers. The oil gland is especially large in swimming birds.

128. Flight.—A bird uses its wings for raising itself from the ground, for sustaining its body in the air, and for moving forward in any direction. All flying birds have a large sternum with a prominent keel, to which large pectoral muscles are attached for moving the wings. We have already described the skeleton of the wing and noticed how this limb has been lengthened, how the terminal bones are reduced in number and consolidated, and how the movements at the "elbow" and "wrist" have been reduced to simple hinge movements; for any rotatory movement at these joints would render less effective the downward stroke of the wing. We must now see how the feathers of the wing make this organ effective for its function by supplying an extended surface suited for striking against the air with such force and frequency that the bird is kept up and driven onwards.

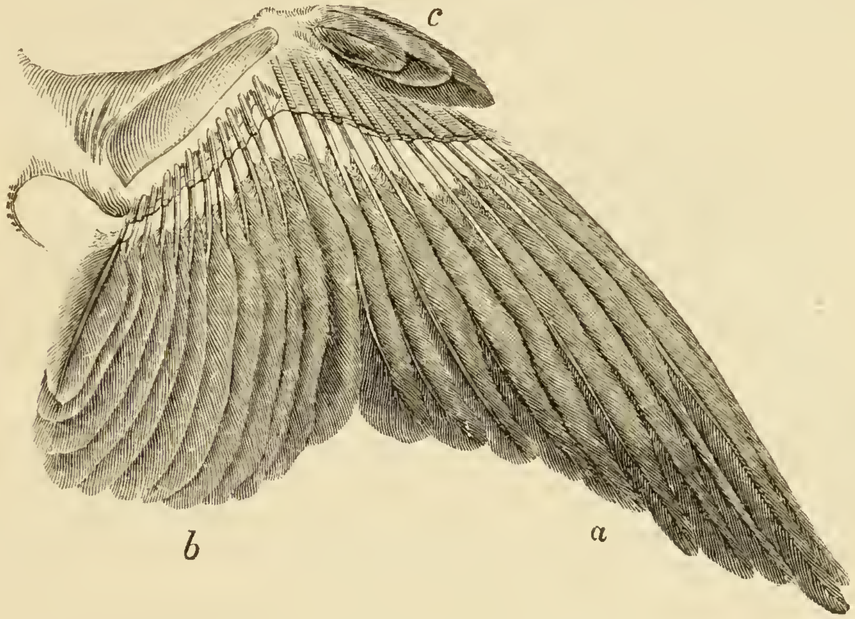

FIG. 191.—Part of wing of pigeon with couverts removed. *a*, Primary feathers; *b*, secondary feathers; *c*, bastard wing. The tertiary quills and the humerus portion of the wing not shown.

Obtain a common pigeon that has been recently killed and examine the wing carefully. Find the shoulder joint, and spread out the wing. Notice that the upper surface is convex and the under surface concave. The largest feathers that fringe the wing are the flight feathers (*remiges* = "rowing feathers"). These large feathers are covered above and below by smaller feathers, called the wing **couverts.** Strip off the couverts and notice where the large flying feathers arise. Ten large flight feathers are attached to the skin and muscle over the metacarpus and fingers—*i.e.* over the bones representing the human hand. These are the feathers farthest from the body, and are called **primaries.** In the pigeon the second and third primaries are longer than the first, and form the tip of the wing. The flight feathers attached to the fore arm are the **secondaries.** Smaller flight feathers attached to the upper arm near the body are called **tertiaries.** A small tuft of feathers borne on the thumb form what is known as the **bastard wing.**

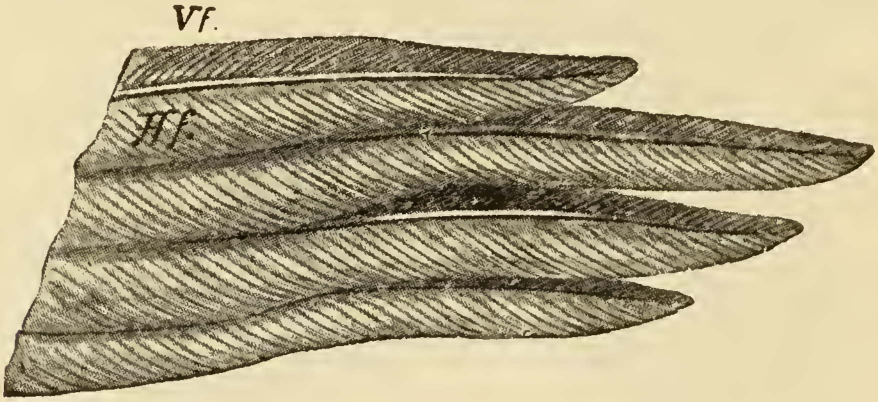

FIG 192.—Tip of wing from below. *Vf,* narrow anterior vane; *Hf,* broad posterior vane.

Wings are of various shapes; but it may be said that as a rule the greater the surface of the wing when outstretched, the greater will be the power of flight. That it is the flight feathers that render the wings capable of serving as an organ of flight is evident from the fact that when a bird is deprived of these feathers it is unable to fly, but recovers this power after renewing them. It is important to notice the arrangement and position of the flight feathers in an extended wing. The two vanes of a flight feather are of unequal width, one vane, the anterior vane, being narrower than the other vane, the posterior vane. The vanes of the feathers do not lie side by side, but overlap each other in such a way that when seen from above all the narrower vanes are on the upper surface, and all the broader vanes on the under surface, and *vice versâ* when seen from below (see Fig. 192). This arrangement and the structure of the vane leads to an almost airtight surface during the down stroke of the wing on the air. In the upward stroke of the wing, resistance is reduced to a minimum by the convex upper surface, firstly by the flight feathers of the hand being turned nearly vertically upwards owing to a bending of the wrist-joint, and, secondly, by the air passing between the other flight feathers, owing to the air pressure on the narrow vanes and the free portion of the broader vanes causing the flight feathers to rotate a little. The whole structure and arrangement of the feathers of a wing is such that in the downward stroke the feathers beat the air with the vanes flat and closed, and this gives an upward and forward impulse to the bird; while the upward stroke is deprived of much contrary effect in the ways just mentioned. The turning of the flight feathers on their long axis during the upstroke of the wing is a movement copied by the oarsman who "feathers" his oar.

The tail of a bird usually consists of twelve long steering feathers—**rectrices**—covered at their bases above and below by tail couverts. The bird uses its tail partly as a rudder and partly for balancing. During flight the feet of pigeons and all singing birds are drawn close up to the body, while birds with long feet, as storks and herons, stretch them out behind.

The power of flight in birds varies greatly. One of the best flyers is the pigeon (fifty miles an hour); another is the swallow (one hundred and twenty miles an hour).

The flight of the domestic fowl is heavy and awkward. This is due to its short, rounded-off wings, the comparatively weak muscles of its breast, accompanied by smaller sternal keel, and by its relatively heavy body, few of its bones being filled with air. The ostrich is incapable of flight, for it has but weak wings, a weak shoulder girdle, a small sternum without keel, and but feebly developed breast muscles. Moreover, it has neither flight feathers nor steering feathers. All the large feathers of its wings and tail have a weak shaft, and its barbs and barbules having no hooks, the feathers form a plume, instead of vanes with a continuous surface. But the ostrich can run faster than a race-horse. Its legs are very tall, owing to the long tarso-metatarsus;

it has but two toes, but these are provided with broad soles to prevent it sinking into the sand. Another running bird is the emu of Australia.

129. The Digestive System of Birds.—Birds have no teeth. The food passes from the pharynx at the back of the mouth into a short **gullet**, and then into a **crop** situated in the neck. The crop is only large in birds that feed on grain ; in it the grain is softened. From the crop the food passes into a glandular stomach to be mixed with digestive juices. It then enters a **gizzard.** This part of the alimentary canal has, except in flesh-eating birds, stout, muscular walls, and generally contains sand and small stones that have been swallowed to aid in grinding the food. Examine the crop and gizzard of a fowl. From the gizzard the food passes into the small intestine, where it is mixed with bile from the liver and pancreatic juice from the pancreas. In the small intestine the nutritious parts of the food are absorbed, and the remaining portion sent on into the large intestine, the end portion of which is called the **cloaca.** The cloaca not only receives the residue of the food, but also the excretion of the kidneys, and, in case of the female bird, the eggs from the ovary.

130. Respiration in Birds.—Air passes through the nostrils or mouth into the trachea, and from thence into the lungs. The lungs are connected with air sacs scattered through the body among the intestines, in the neck, and among some of the muscles. These air sacs have a much greater capacity than that of the lungs themselves. Blow down the windpipe of a dead pigeon, and notice how the breast and abdomen expand. The air sacs are also in communication with some of the hollow bones, thus increasing the buoyancy of the bird. There is no diaphragm in birds. Breathing is accomplished by the action of the muscles of the thorax when the bird is resting or walking, the thorax being enlarged by muscular action that straightens out the ribs and pushes the sternum downward, and decreased as the ribs return to their angular position. But during flight there is no need for the action of special respiratory muscles, for the down strokes of the wings force air out of the air sacs and lungs (expiration), and the elastic reaction of the lungs, aided by the swift passage through the air, forces the air to enter (inspiration). This last mode of breathing explains why a bird never gets out of breath, but settles down calmly after a rapid flight. Respiration—the object of which is to oxidize the blood—is very active in birds, especially during flight, and this rapid breathing leads to rapid oxidation in the tissues, so that the temperature of a bird is higher than that of a mammal—about 108° F. (in man the temperature of the blood is 98·5° F.). So complete is the connection of the hollow bones with air sacs and lungs in some birds that if such a bone as the humerus is broken the bird can breathe, though the windpipe be blocked in some way.

131. Development of the Bird.—A young bird comes out of an egg, being hatched by the heat from the body of the parent bird as it "sits" upon the eggs. The period of incubation varies. For the pigeon, it is about sixteen days; for the domestic fowl, about twenty-one days. Equal warmth supplied artificially, as in incubators, produces the same result. Outside, the egg is surrounded by a chalky shell which has many small pores. Under the shell lies a white membrane, or skin, of two layers, close together for the most part, but separate at wider end. This membrane encloses a slimy, transparent fluid, the albumen, or white of the egg. In the albumen floats a yellow yolk surrounded by another membrane. On the yolk may be noticed a small patch like a little bladder. This is the **germ**. When kept at a proper temperature the germ grows into a young bird. The white of the egg and the yolk are gradually taken up by the growing chick and transformed into the flesh, bones, and down that form the young bird. The air required is obtained through the pores of the shell. When the young bird is fully formed it breaks its prison and slips out. The young of many birds are nearly naked, and helpless, and must remain in the nest to be fed for some time. In the case of other birds, chickens, ducks, and other swimming birds, the young can follow the mother and pick up food at once.

132. Habits of Birds.—Bird life is full of interest, but the subject should be one for the student's own observations in his own neighbourhood. Only a few points can be noted here. Birds live on various kinds of food, and eat more in comparison with their bulk than any other vertebrate. Some live almost entirely on raw flesh, some live on fish, some on insects or the larvæ of insects,[1] some on seeds, fruit, and young crops, while many live on a kind of mixed diet. The bill or beak is adapted for what is required in order to obtain the food (par. 124). The feet also show adaptation to the bird's mode of life (par. 124). Wading birds (storks and herons) have usually both long necks, long beaks, and long legs, as they must find a large part of their food in ponds and streams. The beak of the duck family (ducks, geese, and swans) is worthy of particular note. Examine one. It is broad and flat, and the lower mandible of the beak is a little smaller than the upper one. The upper half of the beak is covered with a soft sensitive skin, that enables the animal to feel its food in dirty water and mud. The edges of the beak are horny, for cutting off aquatic plants and holding its animal prey—small fish, frogs, snails, and aquatic insects. The outer edges of the upper beak and the inner edges of the lower beak have horny, comb-like fringes. So also have the edges of the tongue. Hence, on taking up soft mud with its beak, the duck strains off the water through these horny fringes, and then retains the solid, eatable parts.

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[1] The term *insect* is used loosely for any small invertebrate animal that appears to consist of segments. But spiders, centipedes, snails, and earthworms are not rightly called insects. The word properly used includes only those animals that consist of a series of rings arranged in three distinct segments—head, thorax, and abdomen. The head bears the sense organs, including one pair of feelers, or antennæ. The thorax in the typical insect bears three pairs of legs and two pairs of wings. Bees, wasps, butterflies, moths, gnats, house-flies, dragon-flies, bugs, lice, grasshoppers, ants, crickets, cockroaches, beetles, and locusts are insects. In some of these insects, however, one pair of legs is wanting, as they are represented by a rudimentary knob only. In some (house-flies, bluebottles, gnats), one pair of wings remains undeveloped; in others (the common flea), no wings at all are visible. Most insects are hatched from very small eggs, and after hatching the insect passes through three stages. As it comes from the egg it is called a **larva** (pl. larvæ). The larvæ of butterflies and moths are caterpillars; the larvæ of beetles are grubs; and the larvæ of flies, maggots. The larvæ often pass into a second stage, where they sleep in a cocoon. This is the **pupa** stage. After a time the pupa passes into the **imago**, or perfect insect. The pupa of the butterfly and moth is called from its colour a **chrysalis** (Gk. *chrusos*, "gold"). Most insects, both in the larval or caterpillar stage, and in the adult conditions, do much damage to vegetation. A few are of service to man. Some beetles act as scavengers; the pretty ladybird insect devours the scale insects on plants; bees furnish honey. The silkworm, which is the caterpillar of a moth, forms in the pupa stage a cocoon of silk. The use of insects in fertilizing flowers is mentioned in pars. 62, 63. See also par. 5, p. 16.

Of the numerous birds that live partly on insects and partly on seeds, it is difficult to say whether they do more good by devouring injurious insects and seeds of weeds than they do harm by eating corn and fruit. A bird that may be regarded as very useful is the woodpecker—common in woods in the middle and south of England—for it lives almost entirely on the eggs, larvæ, and insects that burrow in the bark and wood of trees. It has a long, chisel shaped beak, by means of which it can get at the insects beneath the bark and in the wood. Its long, narrow, barbed tongue aids in drawing out its food. Its feet are especially adapted for climbing trees (Fig. 187).

Most birds build a nest of some kind, in which the eggs are hatched. Blackbirds, chaffinches, crows, thrushes, hedge-sparrows, etc., build in trees or bushes ; skylarks, wrens, kingfishers, woodcocks, grouse, and partridges build on the ground or in holes ; jackdaws, house-sparrows, starlings, swallows, etc., nest in buildings. Our English cuckoo does not build a nest, but deposits a single egg in the nests of several song-birds, and leaves the hatching and feeding of the young to the foster-parent.

During the pairing and breeding season, the song-birds pour forth their melodious notes. The male bird is the songster, the vocal powers of the hens being very small. The organ of voice is at the lower end of the trachea, and is called the **syrinx** or lower larynx. Some birds, as the skylark, have several broods during the season, and hence we hear its song until autumn begins. Others, like the nightingale—a bird that does not visit the northern part of England—have only one brood, so that its song ceases before the end of June.

Most birds migrate from the land of their birth to pass the winter in a warmer climate. (Mention some that remain with us all the year round.) The chief reason of migration is the difficulty of obtaining a supply of food, so that birds pass to warmer regions where their food can be obtained. When the land of their birth begins to enjoy warmer weather (birds always breed in the colder regions they visit), and the insects and seeds on which they live begin to reappear, the birds return. The small sand-martins that build their nests in tunnels on the face of sandy cliffs are the earliest to arrive in this country (in March), but they are soon followed by swallows, redstarts, cuckoos, house-martins, nightingales, wrens, swifts, corncrakes, and other summer visitors. On the other hand, wild-ducks, fieldfares, redwings, and woodcocks, that spend their winter with us, go further north to breed during summer. Our summer visitors, after the breeding and moulting seasons are over, begin to prepare for their great southern flight. Corncrakes, nightingales, redstarts, sand-martins, etc., leave in September, and by the end of October all are gone. Before the departure of the migrants they gather together in groups, and these collect until a starting point is found. How the features of land and sea serve for guide-posts is not quite clear, but in some way most of our migratory birds reach the northern part of Africa, where, on the southern slopes of the Atlas mountains and among the oases of the Sahara, warmth and food are found during our winter. Swallows and cuckoos, however, make their winter home in South Africa. During the great migration flights large numbers of the weaker birds perish owing to bad weather, loss of way, exhaustion, and disease.

QUESTIONS ON CHAPTER XX.

1. Give a description of the external characters of a frog. How does a frog obtain its food?
2. Explain briefly how a frog leaps, swims, and breathes.
3. Describe carefully the skeleton of the hind limb of a frog, and show how this is adapted to aid leaping and swimming. Compare it with that of man or that of a quadruped.
4. How does a frog spend the winter? In what condition are its vital activities at this time? Mention other hibernating animals.

5. What is frogs' spawn? How is the egg of the frog hatched? What changes can be observed in frogs' eggs from time to time with the naked eye?

6. Describe the various changes that a tadpole undergoes from the time it leaves the egg until it becomes a perfect frog.

7. Give a description of the skull and vertebral column of a bird. How do these parts differ from the same parts in a quadruped?

8. Give an account of the shoulder girdle of a bird. What is the use of the keel of the breast-bone of a bird?

9. Describe the arrangement of bones and joints in the wing of a bird (with drawing), and the nature of the feathers of the wing. How are the wings moved?

10. Give an account of the bones in the leg of a bird. How would you locate the hip-joint, the knee-joint, and the heel of a bird?

11. Explain how the skeleton and the muscular system of a bird are specially adapted for existence in the air.

12. Why is the domestic fowl a poor flier and a duck a good swimmer?

13. Why does a perching bird not fall off its perch during sleep?

14. Point out, with examples, various forms of birds' feet, and how these forms are adapted to the mode of life of the birds. How is a bird adapted for standing and walking on its two legs?

15. Write out a general description of the external characters of a common pigeon.

16. Carefully describe the structure of a contour feather. How and why does a bird preen its feathers?

17. Explain in a general way how a bird's wing is specially adapted for flight. What are the movements of the wings in flight? Why does the upstroke not counteract the downstroke?

18. To what bone are the tail feathers of a bird attached? How is it enabled to use its tail as a rudder?

19. Write out a brief description of the digestive system of birds.

20. How does a bird breathe? Why is a bird not out of breath after a rapid flight?

21. What do you know of the form and uses of the following parts of a bird: the furcula or merry-thought, the scapula or shoulder-blade, the hip-joint, the tarso-metatarsus, the crop, the air sacs, and the primary quills.

22. Compare, with drawings, the forelimbs of a frog, a bird, and a quadruped.

23. Describe the beak of a bird of prey, a pigeon or common fowl, and a duck. How do you account for the differences in these beaks? For what purposes does a bird use its beak?

24. What are the special characteristics of the skin of the frog, the bones of birds, and the eyes of birds?

25. Name some of the common birds found in your neighbourhood. On what do these birds feed?

26. Why do many birds migrate? Name some of the birds that are only summer visitors in England, and some that are only winter visitors.

27. How is a bird structurally adapted for an aërial existence?

28. Mention some of the habits of five of the following birds: the skylark, the duck, the house-sparrow, the crow, the robin, the magpie, the thrush, the kingfisher, the swallow, the sea-gull, the cuckoo.

29. Give an account of the structure of a bird's egg. How is it hatched? How are the young of birds clothed on leaving the shell?

30. What is an insect? Through what stages does an insect usually pass? When do you notice insect life to be abundant?

QUESTIONS AND EXERCISES ON

ELEMENTARY BIOLOGY,

WITH OCCASIONAL HINTS AND EXPLANATIONS.

Answers should be illustrated by drawings and diagrams whenever possible.

QUESTIONS AND EXERCISES ON CHAPTER I.

1. What is meant by the three kingdoms of Nature? How are these kingdoms often described? In what respects is this division into three kingdoms unsatisfactory?

2. State the chief characteristics or distinguishing marks of living beings.

3. Give a short account of what you already know about protoplasm.

4. Describe the amœba. How do you know that oxygen is necessary for an amœba?

5. Explain what you understand by a *tissue* and an *organ*. Give examples of tissues and organs in the two great classes of living beings.

6. What do you understand by the term *division of labour* as applied to the structure of a plant or an animal? How is increasing division of labour in the animal kingdom accompanied by a difference of structure?

7. How do *inorganic substances* and *organic substances* differ? To which of the two classes would you assign the following: quartz, wood, starch, clay, water, butter, common salt, albumen, fibrin, calcium sulphate, sugar, marble? How would you ascertain whether a white powder was an organic substance or not?

8. In what respects do plants and animals differ? Are the two mutually dependent?

QUESTIONS AND EXERCISES ON CHAPTER II.

1. Explain the general relations of plants and animals to the atmosphere.

2. Why is water of importance to both classes of living beings?

3. What is the chemical composition of starch? How is the starch obtained from rice, wheat, and the potato distinguished? How would you obtain starch from a potato?

4. What substances are found in wheat flour besides starch? Describe the test by which starch is distinguished? What is the source of starch?

5. To what class of organic compounds does sugar belong? How does its chemical composition differ from that of starch? In what important physical property does it differ from starch? Whence do we obtain our supply of sugar?

6. How is *cane-sugar* distinguished from *grape-sugar?* What kind of sugar is obtained from the beet-root and from raisins?

(Glucose, dextrose, or grape-sugar can be produced from cane-sugar by boiling with dilute sulphuric acid. It can also be obtained from starch in the same way. This variety of sugar is also produced from starch by the action of a ferment during the germination of many seeds. Starch is also converted into a soluble sugar with similar properties to glucose by the action of ferments in the digestive fluids of the alimentary canal of many animals.)

QUESTIONS AND EXERCISES ON CHAPTER III.

1. Give a brief description of the chief parts of an ordinary flowering plant.

2. Describe the parts of some regular flower that you have examined.

3. Give some account of a typical pistil, and explain how an ovule becomes fertilized? What does a ripened and enlarged pistil become, and what does it contain?

4. Explain the terms *calyx*, *corolla*, *perianth*, *andrœcium*, *gynœcium*, *ovule*.

5. How are plants divided with reference to the time they live? To which class do the following belong: bean, pea, garden sunflower, foxglove, carrot, teasel, wallflower, rhododendron, oak?

(The division is not a very accurate one, for the duration of the life of some plants depends on the climate and time of sowing. The first three in the above list are annuals, the next three biennials, and the last three perennials.)

QUESTIONS AND EXERCISES ON CHAPTER IV.

1. Give an account of a young vegetable cell. How do older cells differ from young ones?

2. Mention some of the substances found in vegetable cells. What is the special importance of chlorophyll?

3. What varieties of thickening occur on the walls of cells? How do vessels arise from cells? What varieties of vessels occur in plants?

4. Mention the three chief functional tissues of a plant, and describe the epidermal tissue.

5. Give some account of the tissues in a herbaceous stem, such as that of the sunflower or the bean.

6. What is a fibro-vascular bundle? How are these bundles arranged in a one-year-old stem of a dicotyledon? What is the nature of the fibres and vessels in such a bundle?

7. State the chief functions of fibro-vascular tissue.

8. How do you account for the "annual rings" seen in a cross-section of a tree? Why are there no such rings seen in the stem of a palm?

9. Explain the terms *epidermis*, *cuticle*, *chloroplast*, *parenchyma*, *stoma*, *xylem*, *cambium*, *sieve-tube*.

(The *cuticle* is the thickened outer wall of epidermal cells. The *cambium* is the active growing tissue between the xylem and phloëm of a fibro-vascular bundle, and therefore on the outside of the woody part of a trunk. *Sieve-tubes* are long tubes found in the phloëm or bast which have sieve-like plates at intervals, through which strands of protoplasm pass from cell to cell (Fig. 35)).

QUESTIONS AND EXERCISES ON CHAPTER V.

1. Describe a broad bean and the parts of which it consists.

2. Under what conditions does a bean germinate? Describe the early stages of growth until the first foliage leaves expand.

3. Give some account of the structure of the root of a bean plant. What experiment would you perform to find the region of maximum growth in the root? What is a *root-cap*, and what are *root-hairs?*

4. Give a general account of the structure of the stem of a bean plant.

5. Describe the leaves of the bean plant and explain the microscopic structure of a leaf. (For the latter part of this question, see par 52.)

6. Give a detailed account of the flower of the bean or pea, with illustrative sketches.

7. What is the *ovary* of a bean-flower like? What other parts form the central organ of this flower? What does the ovary contain? What changes does the ovary undergo after its ovules are fertilized and the petals and stamens wither and fall away?

8. For what purpose do bees visit the flowers of the bean and pea? What advantage to the flower are such insect visits?

9. What forms the *embryo* of the bean plant? Describe the form and functions of the cotyledons of the bean.

(The cotyledons of the broad bean, though leaves, never assume the functions of ordinary leaves, for they remain in the seed coat, never expanding and becoming green. They serve, however, as a source of food material during the early stages of germination, as they contain a store of starch that is transferred to the radicle and plumule during germination. The transference of starch from the cotyledon and from any part of a plant to another depends on the power a plant has to convert insoluble starch into sugar. This power is due to a ferment in the plant called diastase. The action of diastase may be studied to some extent in a brewery. Barley is made to germinate, and in the process the starch changes into sugar and is transferred to the sprout of the grain. Germination is stopped, and the sugar then produced is used with the help of yeast to form alcohol.)

QUESTIONS AND EXERCISES ON CHAPTER VI.

1. Describe in some detail the rhizome or underground stem of the bracken fern. How do the true roots of this stem arise?

(A rhizome or one branch will have the present year's frond growing from a point near the soft round end, and in front of it will be found the young frond of next year, while in the opposite direction will be the decayed stumps of the fronds of past years. See Fig. 64.)

2. Give a detailed account of the frond of the bracken. What is the structure and function of a frond apart from serving to produce spores?

(The fronds have the same function as the green leaves of an ordinary flower plant, and show the same structure under the microscope. See pars. 51 and 52)

3. What is a sporangium? How and where do we find the sporangia of the bracken? Explain the mechanism by which a sporangium scatters its spores.

4. What is a spore? What is produced when it germinates? Give an account of the appearance and structure of a *prothallus*.

5. What small structures are found on the under surface of a fern prothallus? Explain the functions of these structures.

6. What is meant by "an alternation of generations"? What are the alternate generations in the fern family?

7. Compare the processes of fertilization and reproduction in a bean plant and a fern.

8. Explain the terms *growing point*, *pinnule*, *indusium*, *annulus*, *asexual reproduction*, *sexual reproduction*, *antheridium*.

9. Compare the mode of fructification in the bracken fern, the male shield fern, the polypodium, and the maidenhair fern.

(The spores or asexual reproductive organs of ferns are found in brown patches, or sori, on the underside of the fronds when they are ripe in autumn. Those of the first two are described in the text of the book; those of the common polypodia occur in oblong patches; those of the maidenhair fern occur at the tips of the fertile pinnules.)

QUESTIONS AND EXERCISES ON CHAPTER VII.

1. What elements are found in plants? How do these elements exist in a plant? Which of the elements will be found in plant-ash?

(Plant-ash consists of mineral compounds that are incombustible and not decomposed by heat. Calcium, magnesium, potassium, sodium, and iron compounds would be found in plant-ash, but no carbon, hydrogen, or nitrogen.)

2. From what sources does a plant obtain the food it requires?

3. "Plants cannot make use of the free nitrogen of the air." How is this proved? What exception is there to this statement?

(See Fig. 78. The bean plant and other plants with papilionaceous flowers possess small swellings or tubercles on the roots which contain bacteria, and give these plants the exceptional power of taking in the free nitrogen of the air and of using it for the formation of tissue. The nodules are at first somewhat pink and solid, but later they shrivel, and at last, when the bean has ripened, they become brittle and break up into fragments that are left in the ground along with the remains of the roots.)

4. How would you show that the water required by a plant is taken

in through the roots? Which parts of the roots are engaged in this process of absorption?

5. How do plants obtain their supply of mineral matter? What experiment can you perform to show that a fine insoluble powder cannot be taken up by a plant?

6. What is meant by a *culture solution?* Give the ingredients of a complete water-culture solution. What would be the effect of growing a seedling in this solution, if a soluble nitrate were omitted? if the small quantity of a soluble iron salt were omitted?

7. Describe a method of using water-culture solutions to find the effect of adding or omitting certain mineral salts.

(The solutions may either be used in a darkened bottle as in Fig. 77, or the solutions may be added to insoluble sand or brick powder.)

8. Through which portions of a stem does the absorbed water solution reach the leaves? What experiments will show the water path in plants?

9. Explain the nature of the physical process or processes that cause water and watery solutions to ascend through a plant against the action of gravity. Describe experiments that illustrate these processes.

10. What is meant by the *transpiration* of plants? How would you exhibit it to a class of pupils?

QUESTIONS AND EXERCISES ON CHAPTER VIII.

1. What three tissues may be noticed in a leaf by the unaided eye? How does the upper epidermis of a leaf usually differ from the lower epidermis?

(See Fig. 84. Such a section of a leaf, also, often shows the cut ends of the vascular tissue forming one or more of the veins of the leaf.)

2. What is seen when a transverse section of a leaf is examined under the microscope?

3. What experiments would you perform to show the conditions under which green leaves take in carbon dioxide through their stomata, retain the carbon, and set free the oxygen?

4. "Leaf-green and sunbeam fix carbon and set free oxygen." Explain the meaning of this as fully as you can.

5. What do plants do with the carbon they obtain from the carbon dioxide of the air? Describe an experiment to show that starch is formed in green leaves exposed to the air only when in the light.

6. Describe experiments (*a*) to show that root-hairs are the water-absorbing portions of a plant; (*b*) that the stomata of leaves communicate with air-spaces in the leaf between the cells.

QUESTIONS AND EXERCISES ON CHAPTER IX.

1. What do you understand by the term *respiration?* Which parts of plants are continually respiring?

2. Explain some mode of proving that the living parts of plants are using up oxygen and giving out carbon dioxide.

3. Respiration being a process of oxidation, heat must be produced during the process. How would you show this effect?

4. Compare and contrast the processes of respiration and carbon fixation in plants.

QUESTIONS AND EXERCISES ON CHAPTER X.

1. Explain the terms *pollination*, *fertilization*, *self-pollination*, *self-fertilization*, *cross-pollination*, *cross-fertilization*.

2. What are the hindrances to self-fertilization in the primrose, hazel, and willow?

(A catkin is a scaly group of sessile unisexual flowers. In the hazel there are staminate catkins only; in the willow there are separate catkins of each kind.)

3. Lord Avebury says in his delightful book entitled "Flowers, Fruit, and Leaves," "Wind-fertilized flowers as a rule have no colour, emit no scent, produce no honey, and are symmetrical in form. Colour, scent, and honey are the three characteristics by which insects are attracted to flowers." Illustrate these statements by examples. (The student is recommended to seek the opportunity of reading Lord Avebury's book.)

4. Explain the mode of fertilization in the flower of the Meadow Sage.

(In flowers like the Meadow Sage, which grow in bunches, the lower ones open first. The stamens of this flower ripen and send out their pollen before the pistil is ready, so that in a given bunch the lower flowers are the older, and have arrived at the stage for receiving pollen on the pistil, while the upper ones are only at the stage of discharging the pollen. It is the habit of bees to begin with the lower flowers and work upwards, so that a bee that has dusted itself with pollen from another flower first comes in contact with the flowers whose stigma is ready to receive pollen, and then passes up to flowers that give a fresh supply of pollen, and with this the bee flies to another plant.)

5. How is fertilization brought about in the case of the flower of the bean or pea?

6. Various means have been used to prevent pollen from reaching the stigma of a flower pistil, such as removing the stamens and enclosing the remaining part of the flower in a muslin bag. What do you suppose will be the effect of such means?

(Where both self-pollination and cross-pollination are prevented, the ovules in the ovary of the pistil remain unfertilized, and the pistil shrivels away without any development of seed.)

QUESTIONS AND EXERCISES ON CHAPTER XI.

1. What is a fruit? Of what parts do fruits usually consist? How may fruits be classified?

2. What kind of a fruit is a bean-pod, a wallflower-pod, an apple, a plum, a strawberry, a gooseberry, a blackberry, and an acorn?

(A blackberry is a compound fruit, each small fruit being of the nature of a cherry with the seed in a shell.)

3. Distinguish between a fruit and a seed. Describe the seed of the pea, the apple, and the oat.

4. What advantage to a plant is it that its seeds should be widely dispersed? What are the chief means of seed-dispersal?

5. Describe seeds (*a*) that are dispersed by the wind; (*b*) that are dispersed by clinging to animals; (*c*) that are dispersed by passing through the bodies of animals.

QUESTIONS AND EXERCISES ON CHAPTER XII.

1. Under what conditions do seeds germinate? If you place some mustard seeds to germinate in damp sawdust, one set in a warm room, and one in a cold cellar, what difference would be observed?

2. Compare the germination of the broad bean with that of the kidney bean.

3. Describe carefully the germination of a grain of wheat or of an oat-grain.

4. Why is it that when a seed germinates the root grows downwards and the stem upwards?

(The radicle or main root of a seed is endowed with the property of growing towards the centre of the earth, so that even if a young seedling bean have its root placed horizontally or vertically upwards, the tip will soon curve downwards. The stem is endowed with the opposite property, for it has a tendency to grow away from the centre of the earth. The first property is called by botanists *geotropism* (Gk. *Ge*, "the earth;" *tropos*, "a turning"), and the property of the stem *negative geotropism.*)

QUESTIONS AND EXERCISES ON CHAPTER XIII.

1. Describe an experiment to ascertain which constituents of white light are most effective in carbon-fixation in plants.

2. Carefully describe the effects of growing plants in darkness.

3. What is observed when plants grow so that light reaches them from one side only? Mention other facts that show that the leaves and other parts of plants usually seek to get as much light as possible.

4. How do plants show a susceptibility to alternations of light and darkness?

QUESTIONS AND EXERCISES ON CHAPTER XIV.

1. How is the trunk of the human body separated into two great cavities or chambers? Name the chief organ in each chamber, adding a brief account of the position and form of each.

2. Describe the vertebral column, explaining how the spinal canal is formed.

3. Give a brief description of the atlas and axis vertebræ.

4. Name the chief bones of the skull, pointing out the position of each.

5. Explain the mode in which the lower jaw of man is articulated with the skull, and the nature of the movements it is capable of.

6. What bones constitute the shoulder girdle? Give an account of the bones forming the arm.

7. What bones constitute the pelvic girdle? Describe the bones of the leg and foot.

8. Describe a perfect joint, and give examples of the chief kinds of perfect joints.

9. What bones constitute the thorax? Describe the shape and appearance of one of the larger ribs. How is it articulated with other parts of the skeleton?

(See par. 78. A rib is a curved bone somewhat like a half-hoop. Its posterior or dorsal end is articulated with a dorsal vertebra, or rather with the cavity formed by two vertebræ, to which it is attached by ligaments. Its anterior or ventral end is united to cartilage, and this cartilage connects it with the sternum, or breast-bone. During inspiration the ribs rise, and in respiration they fall again.)

10. Give a short account of the structure and composition of a long bone.

QUESTIONS AND EXERCISES ON CHAPTER XV.

1. Give a description of a voluntary muscle. What is the general property possessed by such a muscle?

2. Explain the mode in which the forearm is raised and straightened again.

3. What are flexor and extensor muscles? Give examples of each. What motions is the thumb capable of in man? Which of these is peculiar to man?

4. Give examples of the three orders of lever in the body of a man or in that of a quadruped.

5. What is a *ligament* and a *tendon?* Where are these structures found? Give examples of each.

6. Give a general account of the nervous system of a man or a quadruped.

(The general system is the same in man and the cat, but the brain of man is more highly developed, and shows more convolutions.)

7. Distinguish between efferent and afferent nerves. What kind of nerve leads to the contraction of a muscle?

QUESTIONS AND EXERCISES ON CHAPTER XVI.

1. Give a short account of the chief organs contained in the trunk of a common quadruped like the cat or the rabbit.

(The horizontal position of a quadruped leads us to speak of the two cavities of the trunk as *anterior* and *posterior*, instead of *upper* and *lower*, as in man. We may also speak of the *ventral* surface of the trunk (Lat. *venter*, "a belly"), and the dorsal surface (Lat. *dorsum*, "a back").

2. Explain the mode in which (*a*) the skull is articulated to the vertebral column in the cat; (*b*) the mode in which the lower jaw is articulated with the skull; (*c*) the difference between the clavicle in a cat and in man.

3. Describe the teeth of the cat, and show how they are adapted for killing and devouring its prey.

4. Give an account of the limbs of the cat. In what respects do the limbs and the mode of walking differ from those of man?

(A man walking "tip-toe" walks in a somewhat similar way to a cat or other digitigrade animal, but the metatarsal bones are not so vertical, nor the heel relatively so high from the ground. Walking "tip-toe" is walking on the toes, and is not the same as walking "on the tip of the toes" as a horse does.)

5. In what respects is the structure and action of a cat's body adapted to a predatory (Lat. *præda*, "prey") mode of life? How does a cat stalk its prey?

6. Explain (*a*) how it is that a cat can see when a man cannot see; (*b*) how it is that a cat's claws are always sharp and a dog's claws blunt; (*c*) how it is that a cat always falls on its feet, and nearly always with little injury; (*d*) how it is that a cat can move so silently; (*e*) how it is that a cat can get through such small holes.

7. What qualities make the cat a useful and pleasant domestic animal?

8. Explain the mode in which a cat raises and lowers one of its fore limbs (see par. 86).

QUESTIONS AND EXERCISES ON CHAPTER XVII.

1. Give some account of the naked-eye appearance and also of the microscopic appearance of the blood of man or the cat.

(The blood of all mammals is substantially similar to that of man described in the text, there being two kinds of corpuscles, red and white, in a liquid plasma, the red having circular discs without a nucleus, though there are differences in size and structure in the different classes. The corpuscles of the cat's blood are rather smaller than those of the man, though they bear, as a rule, no relation to the size of an animal, those of the mouse and the elephant, for example, being about the size of those of man.)

2. State the chief functions of blood. What occurs when blood coagulates?

3. Give some account of the outer appearance and inner structure of the heart. Illustrate your answer by a diagram.

(The heart of man, the cat, the rabbit, the sheep, or other mammal, is in all essential features exactly similar to that of man described in par. 98, and they all have a similar double blood-circulation—a greater or *systemic* circulation, and a smaller or *pulmonary* (Lat. *pulmo*, "a lung") circulation.)

4. Describe the direction of the blood-flow through each side of the heart. How is the blood that leaves a ventricle prevented from flowing back again?

5. What do you understand by *arteries*, *capillaries*, and *veins ?*

(Remember that capillaries are so minute (about $\frac{1}{2000}$ of an inch) that they can only be seen under a microscope. Try to obtain a view of the blood circulating through the capillaries in the web of a frog's foot.)

6. Give some account of the pulmonary circulation, and explain the nature of the changes that the blood undergoes in the lungs.

(Note that Fig. 163 is only a diagram or schematic figure. In the diagram the arteries are on one side and the veins on the other. This is only for the sake of convenience and simplicity. In reality arteries and veins run close together in the various muscles and other organs.)

7. To what is the colour of blood due? How could you illustrate your answer by an experiment? (Par. 97.)

(Remember that it is common to speak of the bright red blood as *arterial* blood, and the dark purplish blood as *venous* blood. This is only correct of the general or systemic circulation. In the pulmonary circulation the reverse is the case.)

8. How does the flow of blood in an artery differ from the flow in a vein? When blood is shed, what changes does it undergo, and to what are these changes due?

9. Describe in a general way the organs of respiration of man or a quadruped.

(The respiratory organs of mammals and the mode of breathing do not differ in any essential respect from those of man. They all have a diaphragm, and show both kinds of respiration.)

10. Describe in some detail the structure of the lungs. In what part of the lungs does the interchange of gases between the blood and the atmosphere take place?

11. Explain how inspiration and expiration are effected by the expanding and contraction of the thorax.

12. Set down carefully the differences between inspired air and expired air. Can the lungs be entirely emptied of air? How does air pass in and out of the lungs when the mouth is closed?

13. What is meant by *ventilation?* How do animals and burning candles affect the air of a room?

QUESTIONS AND EXERCISES ON CHAPTER XVIII.

1. Write out a general account of the alimentary canal.

(The question refers to the alimentary canal of man as described in par. 102. With the exception of the teeth, the digestive apparatus is very similar in all kinds of quadrupeds, and the processes of digestion nearly the same. The stomach of ruminating animals, like the cow, is, however, very complex. Carnivorous animals, like the cat, have also a shorter intestinal canal, and herbivorous animals a longer intestinal canal, than that of man.)

2. What is meant by *digestion?* In what parts of the alimentary canal does the process go on?

3. Where are the salivary glands? What do they secrete? What is the effect of their secretion on certain parts of the food? How would you show this effect? (See experiments, par. 110.)

4. Explain the mode in which food is swallowed. How is food prevented from going "the wrong way"? What occurs if a particle happens to go the wrong way?

(Study Fig. 172. When a particle of food happens to go the wrong way, violent coughing is set up, so that the suddenly expired air may expel the particle.)

5. Describe the shape and position of the stomach. Of what parts do its walls consist? (Study Fig. 174.)

6. What secretion is provided by the stomach? What is the active principle of this secretion? What effect has the secretion on the food in the stomach?

7. Explain the processes of digestion that go on in the small intestines.

8. How is the digested food in the intestines absorbed into the blood?

9. What do you know of the pharynx, the pylorus, the pancreas, and the ileo-cæcal valve?

10. Name and describe the various digestive juices, and explain the action of each on the various kinds of food-stuffs.

11. What is the lymphatic system of the body? How do the contents of the lacteals or lymphatics of the intestines differ from the contents of the general lymphatics during digestion?

(After a meal containing fat the liquid in the intestinal lymphatics is white and opaque, owing to the minute globules of fat that have been absorbed into the lymph-vessels of the villi and passed on. This liquid is termed chyle. In a fasting animal the lacteals contain clear lymph, like that in the other lymphatics of the body. Lymph is described near the end of par. 110.)

12. Describe experiments to show the action of saliva on starch, the action of gastric juice on a proteid, and the action of pancreatic juice on oil or melted fat.

QUESTIONS AND EXERCISES ON CHAPTER XIX.

1. What are the main functions of food? What are the special uses of water in the body?

2. What is the difference between a "food" and a "food-stuff"? Name the three chief kinds of food-stuffs, and point out the differences between them? What substances does an animal require in addition to the three kinds of food-stuffs?

(Food is a general term for any nutritive material taken into the body. Bread, meat, and rice are examples of food. The term "food-stuff" is used to describe the special substances consisting of organic compounds that make up each kind of food. The three chief kinds of food-stuffs are proteids, carbohydrates, and fats, and the names of several food-stuffs in these classes will be found in par. 112. In addition to the three kinds of food-stuffs, animals require water and certain mineral salts.)

3. What are the chief food-stuffs found in milk and bread?

(Milk contains a nitrogenous food-stuff called casein, a fat called butter, a carbohydrate called lactose, or milk-sugar. Bread contains a nitrogenous food-stuff called gluten, and a carbohydrate called starch, some sugar, and some fat. Both contain some mineral salts as well, besides a considerable percentage of water.)

4. Why is some nitrogenous food-stuff absolutely necessary? Why would it be inadvisable to try to live on proteids alone?

(Waste of tissue is constantly going on, and this leads to a loss of nitrogen. Only proteid food-stuffs can replace this loss. See par. 117.)

5. What are the considerations that lead to the need of a "mixed diet" for man?

6. What is the source of the heat of the body? Where is the heat produced? How is it distributed and dissipated?

(The source of animal heat is the oxidation of the digested and absorbed food, for this oxidation is a slow combustion and always produces heat. The combustion does not take place in the lungs, as once supposed, but in all the tissues of the body, for the circulation of the blood brings the absorbed food, which is the *fuel*, to all the tissues, and also the oxygen taken in the lungs. The fuel is of three kinds, mainly starches changed into sugar, fats, and the proteid that is not built up into protoplasm to supply waste of tissue. Wherever the oxidation of this fuel occurs in the body, the blood in that part has its temperature raised, and in its circulating movements distributes it to other parts. The body heat is lost or passed away mainly by radiation and conduction from the skin, by evaporation of sweat, by expiration of air that has been warmed in the lungs, and by the transformation of heat energy into the energy of mechanical work.)

7. "The oxidation of food not only produces *heat*, but generates *force*." Explain this statement.

(The production of animal heat is briefly explained in the previous question. Heat is one form of *energy*, energy being the power to produce work (as explained in "Physiography," Section I.). By the term *force* in the quotation is probably meant "the energy of mechanical work." This also is produced by the oxidation of fuel, for such combustion is the source of the mechanical work of the muscles of the body, as it is of the mechanical work or force supplied by a steam-engine. Experiments show that the active energy of the body is mainly derived from the oxidation of the carbohydrates and fat of the food.)

8. Man and other mammals are termed "warm-blooded animals." What is the meaning of this, and how is the temperature maintained uniform or constant?

(A fish or a frog has a body temperature only a little higher than the water or air in which it lives, as the little heat it produces is lost quickly by radiation and conduction; and, as this is often below the temperature of man, they are often called "cold-blooded" animals. It is not a very accurate term, for their temperature varies with the medium by which they are surrounded, and they are really animals of *variable* temperature. Man and other mammals, on the other hand, are the seat of very active chemical changes that produce so much heat that they have usually a temperature above that of the air in which they live, and so they are termed *warm-blooded* animals. This is not a very good description, for man and other animals are so constructed that they keep a nearly uniform temperature, and are, therefore, better described as animals of *constant* temperature.

The average temperature of man is about 98° F., though the skin is often a little below this, and the internal parts are slightly above it. The heat of the body is produced in the tissues wherever oxidation is taking place, and the heat getting into the blood is well distributed to all parts of the body. The heat thus produced balances that lost from the surface of the body by radiation, by perspiration, and by the expiration of warm saturated air from the lungs. In active muscular exercise oxidation of the muscular tissue is increased, and we breathe more quickly to get the necessary supply of oxygen from the air. More heat is also produced during such exercise, and the body temperature begins to rise. But this heat produces more rapid sweating than the insensible perspiration that goes on at ordinary times, and in the evaporation of sweat heat is used up. Sweat is a watery fluid separated from the blood by tiny tubular glands in the skin, the openings of which are called pores, and in the evaporation of the sweat produced by active exertion, the excess of heat is withdrawn from the body and the temperature kept normal, for a definite amount of heat is required to change every gram of water into vapour. In cold air we are inclined to take more food and more exercise to keep up the body heat. We also wear more clothes, the effect of which is, not to warm the body, but to diminish the rate at which the heat produced in the body is lost.)

MISCELLANEOUS QUESTIONS AND HINTS.

1. Compare some of the chief life-processes in the higher plants and animals.

(Respiration takes place both in plants and animals, but the interchange of gases in the process is relatively much smaller in plants than in animals. Moreover, plants have no separate and distinct organ of respiration like animals, but take in oxygen and give off carbon dioxide over the whole epidermal surface supplied with stomata. Plants, with some exceptions, live entirely on a gas (carbon and dioxide), water, and simple inorganic substances in solution, and from these materials construct and store complex organic compounds. They have no special organs of digestion and absorption that can be compared with the alimentary canal of one of the higher animals. There is, moreover, no system of excretory organs or any discharge of nitrogenous waste such as is found in animals. In plant life constructive processes predominate, in animal life destructive processes. Plants are pre-eminently storers of energy, animals expenders of energy. See par. 7.)

2. "Plants need water for several purposes—to convey the dissolved inorganic material taken in by the roots to the leaves, to render the cells turgid, and for the construction of carbohydrates in the leaf. A constant stream of water is passing through a plant, but the greater part of this is evaporated from the leaves." Describe experiments that illustrate these statements. (See pars. 11, 45, 46, 49, and 54.)

(The action of the cells forming the root-hairs by which the water of the soil is drawn through the cell wall into the stronger solution of cell sap (just as the sugar solution draws water through the membrane in the experiments described in par. 48) may be illustrated by taking a sound potato and boring a deep cavity in one end without splitting the potato. Pare the skin from the other end, and shape it so that this closed end will hold it upright. Fill the cavity with sugar, and then place the potato in a saucer holding about an inch of water. In a few hours the sugar will have become moist, for the cells of the potato draw water through their walls from that contained in the saucer, and pass it on into the cavity to the strong solution of sugar until in time the cavity will overflow.)

3. In what relation do plants and animals stand with respect to the gases of the atmosphere? Is the composition of the air affected by any other agencies than plants and animals?

(See pars. 8, 9, and 10. Though plants and animals affect the composition of the air in opposite directions, it must be remembered that a considerable quantity of oxygen is withdrawn from the air by the slow oxidation of rocks, minerals, and other substances. Carbon dioxide is also sent into the air during the process of decay, and in large quantities from active volcanoes.)

4. Half the dry weight of a plant is said to consist of the element carbon in various combinations. From what source or sources is this carbon obtained, and how does it get into the living substance of a plant?

(After the large quantity of water has been driven out of a plant by drying, the matter left consists of many organic and inorganic compounds, and the quantity of carbon in these compounds forms about one-half by weight. This carbon has been derived from the air and not from the soil—that is, it has been obtained from the carbon dioxide in the air (see par. 10). The air with the carbon dioxide in it enters the plant through the stomata of the leaves, minute openings found chiefly on the under surface, but sometimes also on both surfaces (see par. 24). These stomata open into intercellular spaces in the leaf, and the carbon dioxide passes by osmotic diffusion through the moist cell walls into the cell contents. It thus reaches the small protoplasmic particles of a cell (chloroplasts) that contain the green colouring matter chlorophyll. From the carbon dioxide thus absorbed and from the water in the cell. the chlorophyll granules of a leaf cell can construct, with the aid of sunlight, a carbohydrate such as sugar or starch, the oxygen of the carbon dioxide absorbed being returned to the air (see par. 52). This process of carbohydrate formation, sugar or starch, is called *carbon-assimilation* or *photosynthesis*, as it depends on light, the red and orange rays being most effective (pars. 52 and 70). A potato kept in a warm, moist, and dark cellar will often produce a pale weak plant with long stems and small pale leaves. But it has produced no chlorophyll and no new organic substances, for all such substances contain carbon. It has grown entirely at the expense of the substances stored up in the tuber. It is only the energy derived from light that enables the particles of protoplasm containing chlorophyll to form sugar and starch out of carbon dioxide and water.

The carbohydrates formed in a plant from water and air become in part united with nitrogenous matter obtained through the root to form the more complex compounds termed proteids. Proteids contain not only the three elements found in carbohydrates (sugar and starch), but also nitrogen and a small quantity of sulphur and phosphorus (par. 6).

Both the carbohydrates and proteids formed by plants are largely stored for future use.

Plants that have no green leaves or stems cannot obtain their carbon from the air or use the mineral salts of the soil in the same way as the plants that contain chlorophyll. Such plants are either *parasites* growing and living on other plants, like the dodder of the heath, or they feed on decaying organized matter. Mushrooms, toad-stools, the mould plant, and many other species of fungus are plants without chlorophyll that live on organic matter.)

5. State some facts regarding the daily opening and closing of flowers. What is a "Floral Clock"?

(In many plants whose flowers persist for several days, the flowers open in the early part of the day and close into a bud in the later part, the time of opening and closing varying in different flowers (par. 74). This periodical opening and closing is probably connected with the insect visits to the flower, the flower opening when the particular insects that visit it begin to swarm, and folding when the insects retire, lest the pollen should be exposed to the dew or other dangers.

By observing the daily opening and closing of many flowers, the great Swedish botanist Linnæus, and after him other botanists, constructed a table of times which is fancifully called a *Floral Clock*. It should, however, be remembered that the time varies somewhat with the locality and season. Dr. Brown gives the following as the approximate times for the plants named, the name in italics in brackets being the scientific name :—Bindweed (*Convolvulus Sepium*) about 3 A.M. ; goat's-beard (*Tragopogon pratense*), 4 A.M. ; poppy (*Papaver nudicaule*), 5 A.M. ; *Convolvulus tricolor*, 6 A.M. ; white water-lily (*Nymphæa alba*), 7 A.M. ; pimpernel (*Anagallis arvensis*), 8 A.M. ; marigold (*Calendula arvensis*), 9 A.M. ; *Mesembryanthemum glaciale*, 10 A.M. ; Star of Bethlehem (*Ornithogalum umbellatum*), 11 A.M. ; purslane (*Portulaca oleracea*), midday ; *Scilla pomeridiana*, 2 P.M. ; *Mirabilis jalapa*, 5 P.M. ; *Silene noctiflora*, 6 P.M. ; while *Cereus grandiflorus*, *Cooperia*, *Convolvulus purpureus*, and others do not open until after dark.

A fuller table constructed for Innsbruck, lat. 47° N., is given in Kerner and Oliver's "Natural History of Plants." Compared with the table of Linnæus constructed for Upsala, lat. 60° N., it appears that flowers both open and close later at the more southern station.)

6. What becomes of the food taken by an animal? What becomes of the animal itself after death?

(The food taken in by an animal first undergoes the process of digestion, a process, or rather, a series of processes, that produce changes in the food so as to render it capable of being taken into the blood (see pars. 104 to 109). In the case of food converted into sugar and peptones, there is direct passage from the alimentary canal into the blood stream, but in the case of the emulsified fats the food must first be taken up by the lymphatic vessels and then passed into the blood-stream (par. 110). From the blood the food passes into the surrounding tissues, and there it is oxidized into carbon dioxide, water, and urea, either very soon or after having been converted for a time into the tissues of the body. These waste products pass off by the lungs, kidneys, and skin.

After death the complex substances that formed the body of the animal (or plant) begin to decay or putrefy, *i.e.* to be resolved into simpler compounds, the change being largely produced by the agency of minute living forms termed germs or *bacteria*. In decay the complex organic bodies get more oxidized and split up under the influence of these minute agents into such simple compounds as water, carbon dioxide, ammonia, methane, and sulphuretted hydrogen, which pass into the air. Only the denser parts, such as the mineral portion of bone or the dense woody tissue of trees, are able to resist decay for a considerable time, though finally the organic bases of these decompose and leave the mineral matter as a powder to pass into the soil.

7. Explain the formation of the green scales which are frequently seen on the surface soil of a fernery. Whence do they arise? What happens to them if they are allowed to grow? (King's Scholarship, 1902.)

(The green scales are the prothalli of ferns, and have arisen from spores. See par. 41.)

8. The "heart" of a cabbage or lettuce is of lighter colour, sweeter taste, and more tender texture than the external leaves. How do you explain these differences? (King's Scholarship, 1902.)

(The leaves forming the heart of a cabbage or lettuce are shut out from the light, and light is essential to the formation of chlorophyll. Hence they remain pale (par. 71). They are sweeter because the chlorophyll in the outer leaves has a somewhat acrid taste which is absent from them, and because they contain a larger proportion of some kind of sugar in their cells. They are of more tender texture because they are younger and contain a greater proportion of soft parenchyma cells and less fibrous vascular tissue.)

9. After a long run a dog pants rapidly and throws out his tongue. To what chemical changes are these actions due? Name the organs specially involved in the changes in question. (King's Scholarship, 1902.)

(During the rapid run of the dog its leg and some other muscles have been specially active. This has led to the rapid oxidation of muscular tissue and to the production of carbon dioxide and heat. The need of more oxygen than usual, and to the need of bringing the temperature to the normal (see answers to Questions 6, 7, and 8 in last chapter), causes increased respiration, the panting being more noticeable after exertion in the case of the dog than in the case of man, the cat, or other mammals. This is due to the fact that the dog has no sweat glands in the skin, so that the increased need of oxygen and the reduction of the heat must both be effected by the increased rate of breathing brought about by the increased activity of the respiratory muscles. The ordinary rate of breathing in the dog, about 25 breaths a minute, increases to 300 breaths a minute after a long run. This accelerated rate of respiration leads to the removal of a large quantity of water from the lungs, and the evaporation of this water from the lungs produces a considerable cooling of the body, just as the evaporation from the skin does in the case of other mammals. See answer to Question 8 of last chapter.)

10. The bones of the skeleton are useful, (1) as affording points of attachment for the muscles, (2) as affording protection for delicate tissues and organs. Give examples of each of these uses. Do not give the technical names of the muscles. (King's Scholarship, 1902. See pars. 76 to 79 and par. 86.)

11. What is the structure and use of buds?

(A bud may be regarded as an undeveloped stem or branch. It consists of a short stem terminated by a growing point and enclosed by closely overlapping rudimentary leaves. As growth proceeds the short stem elongates, and the leaves develop and become separated from each other, the youngest being nearest the tip (see par. 31). In some cases, however, the stem remains short, and the leaves of the terminal bud form a compact head round this short stem, as in the cabbage and lettuce. In all flowering plants, stem and leaves originate in the way just indicated. Besides a *terminal* bud at the end of a stem or branch, many trees produce during summer *lateral* buds in the *axils* of the leaves (par. 15). When the leaves fall off in autumn the buds remain, and it is instructive to examine winter twigs and branches to note the condition of the buds. Their position to the axil of the leaves may even then be inferred, as the scar of the fallen leaf still remains beneath them. Buds vary considerably in their nature and size, and they have generally some arrangement for protection from cold and rain, many have enveloping hard scales, others are covered with a gummy exudation, while others have an interior woolly lining beneath the outer cover.

The scaly leaves covering young buds fall off as the buds open out in spring and summer, leaving closely set rings of scars, and the distance between one set of scale-scars and another marks a year's growth. Twigs of sycamore, horse-chestnut, and ash should be examined in winter and spring, and the leaf-scars, scale-scars, and condition of the buds noted. Sections of the buds will show the internal arrangements. Some buds on opening give rise to flowers. These are known as flower-buds.

12. What are the simplest functions which distinguish living animal matter from inanimate matter? (King's Scholarship, 1903. See par. 2.)

13. Explain why food and rest are necessary to overcome the effects of muscular fatigue. Why will food alone not suffice? (King's Scholarship, 1903. See par. 119.)

14. Explain the influence of light on a growing plant. Illustrate your answer by reference to the changes in a ripening and germinating bean. (King's Scholarship, 1903. See pars. 69, 70, 71, 67.)

15. In an agricultural experiment a number of different manures were applied separately to patches of similar uncultivated mixed grass land. The results were of two kinds. (*a*) The general growth was increased in all the patches. (*b*) The crops had different appearances in the different patches. Comment on these results. (King's Scholarship, 1903.)

(Manures contain the elements or inorganic food materials required by plants in varying proportions. (See par. 46.)

(*a*) The general growth was increased in all the patches. From this it appears that all the manures contained food materials suitable to the various grasses, etc. They thus promoted the growth of all the plants so that the manured patches were distinguishable from the surrounding unmanured land.

(*b*) The crops had different appearances in the different patches. Hence it appears that one manure contained food materials which favoured the growth of one or more of the plants in the patch, more than it favoured others, for some plants require more of a certain food material than others. Thus clover requires an abundance of lime. Another manure might be deficient in some important plant-food, *e.g.* in nitrogenous compounds.)

16. What is the chemical composition of starch and of sugar? How does their chemical constitution suggest an insight into the way they

are formed in nature? (See pars. 4, 20, 54. Certificate Examination, 1903.)

17. Explain what you understand by an organ. Illustrate your explanation with reference to the liver, the kidney, and the eye. (Certificate Examination, 1903. See pars. 4, 75.)

18. A school museum contains, among other things, some dandelion fluff, a dish of marrowfat peas, a few nodules of garlic, and some hawthorn berries. How could you employ these to illustrate a lesson on plant germination?

(Certificate Examination, 1903. See pars. 64, 65, 67. The dandelion seed is in the fruit-covering at the lower end of the fruit (Fig. 104), and will germinate under suitable conditions much in the same way as the cabbage seed (Fig. 111). The seed of the haw or hawthorn berry is inside the stony endocarp of the fruit, and after a time bursts its way out on being set. The nodule of garlic, like the bulb of an onion, is really a very short flattened stem below, from which thick fleshy leaves arise. It may be germinated over water like a hyacinth bulb. Roots will grow below from the base of the stem and leaves above, the nourishment being drawn from the thick fleshy leaves.)

19. On what food-principles do (*a*) cattle, (*b*) dogs, depend for their sustenance? Which articles of food commonly supply these principles?

(Certificate Examination, 1903. See pars. 112 to 116. The tissues of cattle and dogs are formed of the same nitrogenous and non-nitrogenous compounds, and both require the same kind of food-stuffs or food-principles to form new tissue and repair waste. Cattle are herbivorous animals, and must obtain the required proteids, carbohydrates, and fats from the vegetables (grass, flowers, grains, etc.) that they eat. Vegetable substances consist mainly of water and carbohydrates with small quantities of proteid. Cattle are obliged to eat large quantities of these substances to satisfy their needs. As the food-principles in vegetable substances are mostly enclosed in coverings of indigestible cellulose, cattle require a long intestine to offer a large surface for absorption. Dogs are carnivorous animals like cats, and obtain their food from animal products (flesh, blood, milk, etc.), which contain a large proportion of proteid, etc., in a concentrated form. (See par. 91.))

20. Explain why it is necessary to bank up celery and potatoes with earth in the later stages of their development. What happens to a potato which becomes exposed to light during its growth?

(Certificate Examination, 1903. Celery must be banked up with earth in the later stages of its growth in order to keep it wholesome by preventing the production of chlorophyll and certain harmful cell-products of this plant under the action of light. The banking-up with earth to keep out the light not only produces a blanching of the leaf-stalks and stem, but also increases their growth (see par. 71).

A potato is a tuber, and forms the swollen end of a lateral underground branch stem. The "eyes" are really small buds from which new branches will grow, the bulk of the potato serving at first as a store of nourishment. After planting a tuber, the main axis of the shoot passes upwards into the light, and the unfolding leaves of this carry on the work of assimilation. Branches from the main axis arise, and at the ends of these new tubers are produced, if they are kept in the dark by being earthed up. Keeping the lateral branches below the ground not only leads to the production of tubers, but causes these auxiliary stems to increase, and so a heavier crop is obtained. Allowing the branches or tubers to come above the ground causes them to develop into ordinary shoots with green leaves.)

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